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IMPROVEMENTS TO FUZE TEST METHODS AND EQUIPMENT AND DEVELOPMENT OF NEW MONITORING TECHNIQUES (for MIL-STD-331)

October 1975

Technical Support Directorate

U.S. ARMY ARMAMENT COMMAND
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This report descirbes investigations to improve several fuze environmental tests from MIL-STD-331, Data measurement programs were performed on the Jolt and Jumble test equipment. These programs led to improvements which resulted in longer equipment life and increased standardization of test facilities throughout DOD and GOCO plants. The data was analyzed using both time history and shock spectrum methods. Also, systems were developed to monitor the Jolt machine and drop tower to verify that these

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facilities are conforming to the requirements of the military standard. The Jolt machine monitoring system confirmed peak g-level and pulse width and the drop tower monitoring system verified projectile impact angles. Lastly, test methods such as Fungus, Waterproofness, Salt Fog, Dust and Vibration were updated to include recent advances in environmental test technology. Several recommendations made in the course of this investigation were accepted by the DOD Fuze Engineering Standardization Group and resulted in revisions to MIL-STD-331.

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INTRODUCTION

The quality and reliability of fuzes depend greatly on their methods of testing. There is an ongoing effort by the DOD Fuze Engineering Standardization (FES) Working Group to insure that these arming devices be subjected to state-of-the-art testing technology. As part of this task, every environmental test method in MIL-STD-331 is periodically reviewed (at least once every five years) to determine first, if the test method is outmoded, and second, if the test procedures can be improved. A test becomes outmoded when it is no longer applicable because of changes in field environments, or else it has become obsolete because of better methods available for testing. Tests also require improvements when there has been confusion over vague or inappropriate procedures. This confusion results in poor standardization from one facility to another and raises a question of whether the fuze is being subjected to the proper tests. Therefore, it must be the goal of fuze test engineers to bring the problems found in conducting specified tests to the attention of the Fuze Engineering Standardization Group, and instigate improvement programs applying the latest advances in technology to the solution of these problems.

This project came into existence at the Frankford Arsenal primarily through the efforts of the late Vernon G. Ames, along with several members of the FES. As an engineer in the Environmental Branch and as a member of a standardization panel, Mr. Ames recognized deficiencies associated with several fuze test methods in MIL-STD-331. A program was then proposed by Mr. Ames to investigate the problems, and offer reasonable alternatives for fuze test improvement. The proposal was accepted and funded as an MM&T project (Nos. 5706310, 5736310 and 5746310).

Initial inspection of MIL-STD-331 revealed several test methods in which improvements could be made. The Dust test and Fungus test were outmoded. That is, there existed newer and better means to perform them. In the Salt Fog test the concentration of salt was too high and unrealistic. The requirements in the Waterproofness test were found inadequate for hermetically sealed fuzes. The operability requirements, after a Five Foot Drop test, were in some cases too severe and unrealistic, while the test levels in the Transportation Vibration test were too mild. In the Jolt test and Jumble test, the test equipment appeared to be outmoded. In addition, there was no uniform technique for monitoring the Jolt test shock environment. Finally, no system existed which accurately confirmed projectile impact angles in the Five Foot Drop and Forty Foot Drop tests.

This report concentrates on the investigations of four of the problems. They include the Jolt test, Jumble test, Jolt machine monitoring and Drop test measurements of projectile impact angles. These problems necessitated the purchasing of special equipment, and also required extensive data measurement

and test and evaluation programs. The improvements made to the balance of the test methods are not described in detail in this report. In most instances, their solutions were less complicated and merely required a re-writing of the appropriate test method.

JOLT TEST

Background

The Jolt test Method No. 101 of MIL-STD-331 was developed about 40 years ago. At that time it represented the environment a fuze might see, if it were carried on an Army caisson over rough terrain. Since then, the fuze environment has changed, but the Jolt test has remained. Over many years, experience has shown that the Jolt test is a good indicator for determining how well the fuze is fabricated. In this test the fuze is subjected to repeated shocks from a 4" drop height onto a padded wooden anvil. After 1,750 jolts in each of three directions, the fuze is inspected for component damage or fastener loosening. The test requires that the fuze, although not necessarily operable, must be safe to handle.

The question often arises as to how well the existing Jolt environment is representative of the real world. There is a dearth of known field data to support the test. It would seem that with the measurment of technology available today, investigations into the fuze transportation environment would be done. However, the author has found no recent instances where such measurements were documented. Since little negative feedback has been received about fuze performance in the field, the Jolt test will remain part of the future MIL-STD-331. That does not mean the test method cannot be improved. In particular, the test machine requires modification.

This investigation was initiated because of the problems associated with the special equipment required to Jolt test fuzes. The equipment consisted of a unique shock machine for which no clearly defined test levels existed. The specification of a machine, rather than well defined performance levels, surfaced two immediate problems. First, it was very difficult for fuze engineers to design their items to pass the Jolt test because of a lack of knowledge of the shock environment. Second, it was impossible to verify that standardization existed through fuze test facilities, because there was no standard to compare one Jolt machine's performance against another. A test program was therefore developed which first established a "standard Jolt environment". Then, data was acquired to ascertain the degree of standardization within a given Jolt machine. In addition, an attempt was made to improve the test method. This involved altering both the Jolt machine and the test procedures and comparing these results against the standard environment. In modifying the machine, easier to procure plastics were substituted for the wood arm and anvil, and leather pad. These plastics were tested to determine if they could produce a similar shock environment and yet wear significantly better than the standard materials.

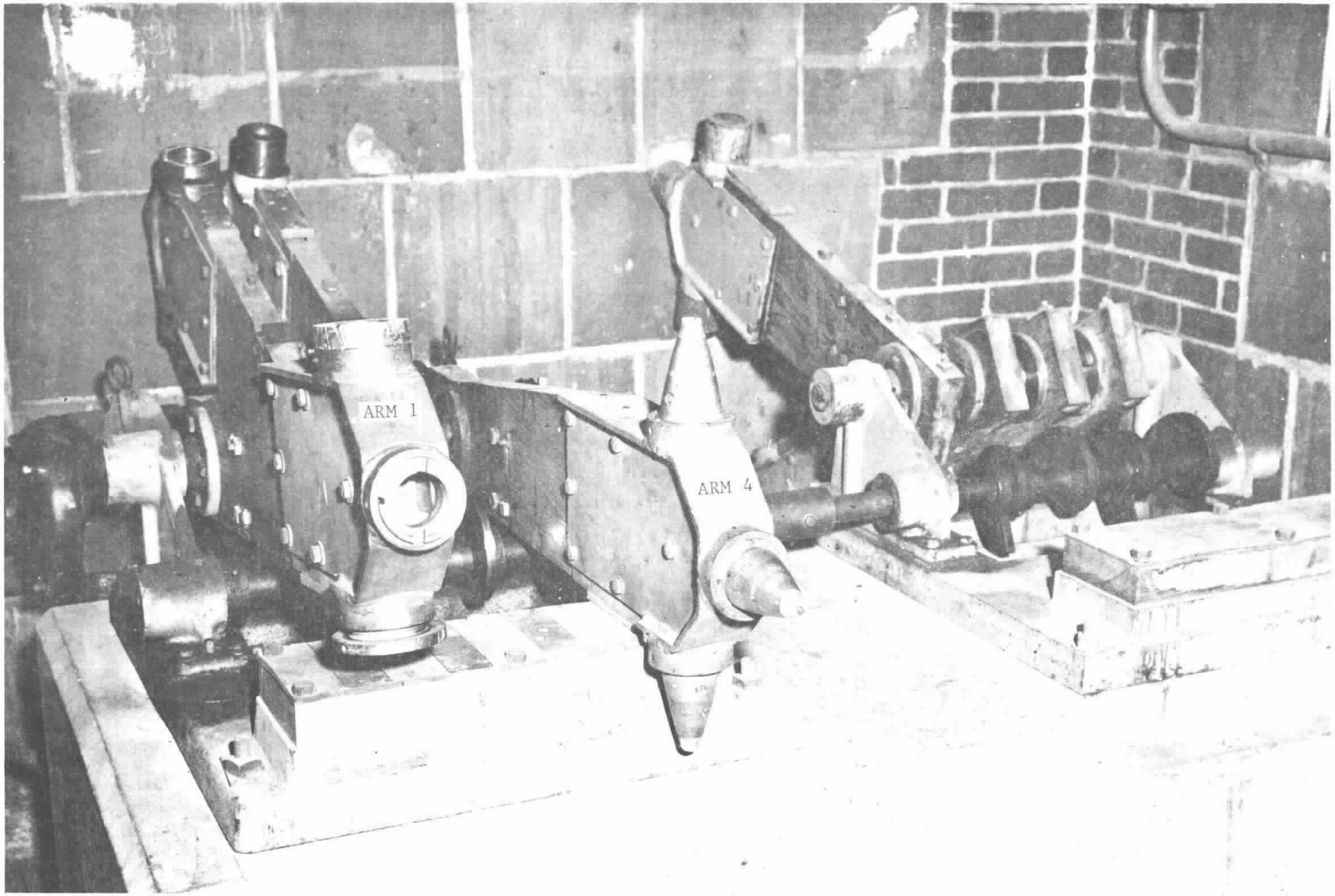
Description of the Jolt Machine

Figure 1 shows the Jolt machine in use at the Frankford Arsenal. The machine consists of four wooden arms pivoted side by side on a common shaft. Each arm has a cast iron plane bearing to allow free motion about the shaft. The free ends of the arms are elevated 4" by cam action and then allowed to drop freely onto a leather-padded, wooden anvil. The cams are offset 90° on the cam shaft so that the arms impact one at a time, at approximately even time intervals. The purpose of the leather pad is to absorb some of the impact and extend the life of the arm and anvil. A metal jacket is fastened over the free end of the arm to provide additional protection to eliminate wearing of the arm in the impact area. The jacket is provided with three threaded sockets in which the fuze or fuze component can be mounted. The sockets are located so that the test item can be oriented in three directions, i.e., "nose-up", "nose-down", "fuze axis horizontal". The size of the fuze dictates whether direct mounting can be used or an adapter is required. The entire assemble of the Jolt machine rests on a concrete foundation.

It is interesting to note the path of the shock to which a test item is subjected. The shock is produced by the change in velocity of the free falling Jolt arm in coming to a zero velocity condition. The contact area is the metal jacket hitting the leather pad. From here, energy is absorbed and transmitted down through the wooden anvil, into the concrete foundation, and back up into the arm. Some energy is passed down to the bearing and shaft, and the remainder finds its way back through the arm and jacket to the fuze. There is enough energy transmitted back to the arm so that rebounds occur. The metal jacket and wooden arm act as stiff springs and tend to transmit most of their energy to the test item, while the leather pad, which is relatively inelastic, tends to absorb the shock. Since the pivoted Jolt arm is allowed to freely rotate, it is possible to place the arm in an inactive condition by elevating the arm until it clears the cam shaft. Any number of arms can be operating at a given time.

Jolt Test Procedure

Under normal operation all four Jolt arms are in an active condition. Since each arm can hold three fuzes, a total of twelve fuzes can be tested at the same time. When fewer than twelve test items are available, dummy fuzes or fixtures are used to simulate the weight of these test items. The drop height of each arm must be $4 \pm 1/4$", and the machine must be inspected to insure that screw and bolt connections are tight, as well as that the arms have no breaks or cracks. In addition, the leather pad must not be overly worn or have breaks or tears. When all the above conditions have been met, the machine meets MIL-STD-331 Test Method 101 specifications.



Note: Arms #1 and #4 are in an active condition; Arm #1 is loaded with dummy weights.

Figure 1. MIL-STD-331 Jolt Machine

Problem Areas

On paper, the Jolt machine appears to be a good, economical way to test a fuze for ruggedness. However, somewhere between the drawing board and the test facility standardization has been lost. The outcome is that all fuzes do not see the same environment throughout the Jolt test. This point requires further explanation. There are several parameters which effect the shock environment. The most important of these are:

1. Weight of the Fuze: From Newton's Second Law that $F = \frac{W}{g} A$, for a given force "F", if the weight "W" of the system is increased the acceleration "A" will decrease. NOTE: ("g" is a gravitational constant). In this case, the weight of the system is the total weight of the loaded Jolt arm. The arm is not a massive structure, and the net weight of the test items on the arm is the same order of magnitude as the weight of the unloaded arms. Therefore, a change in test item weight can significantly change the weight of the system. This results in a heavier fuze being subjected to a lower acceleration level.

2. Position of the fuze on the Jolt arm: In the "nose-up" and "nose-down" orientations, the fuze sees a shock which generally approximates a half-sine pulse. However, in the "fuze axis horizontal" orientation, the pulse shape is somewhat modified. In addition, it will later be shown that the input acceleration levels in this orientation are significantly greater than "nose-up" or "nose-down".

MIL-STD-331 states that "fuzes in the horizontal position should be oriented to expose the maximum Jolt effect, which are considered to be the most vulnerable planes of weakness". The determination of these most vulnerable planes is at the discretion of the fuze designer. Due to the complexity of the small fuze components, the designer may not recognize what should be termed "the most vulnerable directions of weakness"; hence, that information is not passed down to the test facility. In practice then, when a fuze is mounted in the horizontal position, its orientation is generally not controlled, and it is dependent on the mating of the fuze and horizontal socket threads.

3. Location of the arm on the shaft: This parameter was investigated to determine the degree of standardization within a given machine. The question to be answered was whether or not one Jolt arm would produce the same shock environment as another arm under a similar test condition.

4. The number of active arms: Many times a sample, of a given lot of fuzes to be tested, contained fewer than twelve test items. In this instance, set-up time was consumed in loading Jolt arms with dummy fuzes or fixtures. If it could be shown that the shock produced, for example, by arm #1 had little

or no effect on an adjacent arm, then two benefits could be realized. First, set-up time would be minimized, because it would not be necessary to use all four arms. The impact of the arm loaded with dummy fuzes would have no effect on the arm loaded with test items. Therefore, it would not be necessary to load additional arms with dummy fuzes. Secondly, the arms would not be shocked as often, resulting in longer life of the test machine. The net result would be a cost savings of manpower and machinery.

5. Arm material, pad material and anvil material: Another problem area which has been recently recognized is when the arm, pad or anvil requires replacement. Unweildy procurement cycles are commonplace due to the scarcity of wood and leather meeting test drawing specifications. In addition, the physical characteristics of the materials do not tend toward a high degree of standardization. For example, the properties of hardwood will vary according to the grain cut. Also, leather is difficult to machine to a uniform 3/16" thickness. For these reasons, alternate materials for the machine components have been investigated to see if they are not only easier to procure and machine, but also to see if they can wear better, and hence, provide longer test life.

6. Condition of the leather pad: It is fairly well recognized, and it has been documented in MIL-STD-331 that as the leather wears due to repeated impacts in the same location, the acceleration test level will increase. Since the attempt was being made to find an alternate material for the pad, this parameter was not investigated.

Although the above is not a complete list of the parameters affecting the Jolt environment, it seems comprehensive enough to determine what degree of standardization exists, as well as indicate how the existing Jolt test can be improved.

Test Program

In developing an adequate test program, it was necessary to consider what were the main objectives of data measurement. Concerning the particular problem areas of the Jolt test, those objectives were as follows:

1. Determination of the existing Jolt test environment. Since much of the project's effort was concerned with comparison of acceleration test levels, it was logical to begin the test program by defining a standard environment. This standard was developed by measuring the conditions a fuze would see while undergoing a Jolt test according to MIL-STD-331, Test Method 101. While it was possible for a fuze to be located on any one of the four Jolt arms, the "standard" location was considered to be arm "1". Of the three positions in which the fuze could be oriented, the "nose-up"

position was chosen as "standard", for this particular study. Concerning the test load, at first it seemed logical to define a standard as "zero external load". However, when a real test condition was considered, there was some external load due to the weight of the test items or dummy fuzes. Therefore, a simulated load of approximately 3 pounds per fuze or 9 pounds per Jolt arm was defined as "standard". Taking into account the requirements of the MIL-STD-331 test procedure, the "standard Jolt test environment" was then defined as: "arm #1, nose up, 9 lb. load, 4 arms active".

2. Determination of the degree of standardization. To meet this objective, it was necessary to monitor several locations on the machine where test items or dummy fuzes might be positioned. For determining the uniformity of test conditions on a given arm, the "nose-down" and "fuze axis horizontal" positions of arm #1 were monitored. For comparing one Jolt arm against another, arm #2, arm #3, and arm #4 were monitored in the "nose-up" position. For this objective, determination of the degree of standardization, the test program was concerned with the test facility's ability to provide the same shock to a given test item, independent of the item's location on the Jolt machine.

3. Determination of the effect of altering the shock parameters. In this part of the test program, the Jolt machine was operated in violation of the test procedure of MIL-STD-331. This phase would indicate whether or not the Jolt test might be improved. To determine the effect of one Jolt arm on another, only one arm was put in an active condition. This test was done on Arm #1 while monitoring the "nose-up" position. By comparing the results of arm #1 with one arm operating to the "standard", it was possible to determine whether there was any significant change of the test environment, and hence, whether it was necessary that all four arms operate at all times. The effect of eliminating dummy fuzes mounted on a test arm when insufficient test items were available was investigated. If the two test environments, fully loaded arm and partially loaded arm, would be similar, then it would not be necessary to use dummy fuzes at all. Accordingly, arm #1 was monitored with both the "nose-down" and "fuze axis horizontal" dummy test fixtures removed. Lastly, the effect of changing the arm, pad and anvil materials was investigated. Wood was replaced with cast nylon, and leather was replaced with polyurethane.

The next step in the development of the test program was to choose an acceptable data acquisition system. Since measurement of a dynamic environment was anticipated, it was necessary to establish a desired frequency response of the recording instrumentation. From limited quantity of previous

Jolt machine calibration records, it was apparent that the main shock pulse was approximately 2 to 3 milliseconds in duration. Although some higher frequencies were superimposed on top of this main pulse, the author felt that there was little need to be concerned with frequencies above a few thousand Hertz (beyond this point, the fuze structure tends to attenuate the input shock).

Finally, the test program had to consider the question of how much data was enough. Since one of the concerns of the Jolt machine was its ability to reproduce a given shock, the decision was made to record 30 jolts for each test condition. The feeling was that this would provide more than enough data for the analysis phase. Table 1 lists all of the conditions of the finalized test program.

Instrumentation

Figure 2 depicts the data acquisition system used to measure the Jolt test shock environment. The transducer used was an Endevco Model 2224C piezoelectric accelerometer. Its output voltage (proportional to acceleration) was fed thru a "zero drive" signal conditioning system. This system consisted of an MB "line driver" and a Model N400 amplifier, and it was used because of the long distance from the Jolt machine to the recording instrumentation. "Zero Drive" had the effect of eliminating signal loss due to excessive cable length. The time histories were stored on a Sangamo Model 3562 FM magnetic tape recorder. The data acquisition system's frequency response was flat to about 6000 Hz limited by the choice of a transducer.

The accelerometers were bonded onto adapter fixtures. These adapters (see Figure 3) were normally used to test 30MM fuzes and were chosen because of their proximity to a real test condition. Two other factors influenced the choice of using 30MM adapters. First, by mounting on the adapter, the flat surface was sufficiently large to allow for a good bond between the accelerometer and fixture. In addition, when the adapter was attached to the Jolt arm, the system was essentially stiff enough so that data measurements were representative of the input to any fuze whose weight was approximately three pounds. That is, the natural frequency of the fixture threaded in the Jolt machine was high enough (above 3000 Hz) as not to effect the data in the primary range of interest. (The shock pulse being 2-3 ms). The bonding adhesive used was commercial dental cement which had been successfully tested in the Environmental Branch to 1400 g's, 2 ms, half-sine pulse.

Data Reduction

As mentioned previously, the test program took into account the objectives of data acquisition. Similarly, data reduction took into account the objectives of the data analysis. This included preparing the data into a form suitable for

obtaining a comprehensive evaluation of the Jolt test shock environment. The procedures involved first, reducing the tape recorded data into oscillograms, and then further reducing the data into shock (response) spectra.

The oscillograms contained information in the form of time histories which described the Jolt environment in terms of acceleration as a function of time. The useful information obtained from oscillograms included peak g-level, the period of the shock pulse and the pulse shape description. On simple pulses such as a half-sine or terminal peak sawtooth, this information probably would have been sufficient for comparing one shock against another. However, the machine did not provide only a simple pulse. There were higher frequencies superimposed on top of a primary shock pulse which tended to distort the fuze test environment. Those high frequency components needed to be considered when evaluating the Jolt environment, and for this reason, oscillograms were not sufficient. Therefore, the shock spectrum analysis method was also used in evaluating the shock.

A shock spectrum is basically a plot of acceleration vs. frequency. Each frequency represents the natural frequency of a single degree of freedom system, and the accelerations are the maximum accelerations each single degree of freedom system would experience when subjected to the given shock. For the example of the Jolt machine, a shock spectrum, obtained at the attaching point of the test item, can be used to determine the input acceleration that a fuze would see, if it were considered as a one degree of freedom system subjected to the Jolt shock. The spectrum is important for fuze designers when performing structural analysis.

The following procedure was used in reducing the data. First, several oscillograms were produced for a given test condition. Next they were inspected to see that the time histories were not changing from one curve to another. Then shock spectra were obtained using a Spectral Dynamics Model 320 Shock Spectrum Analyzer and a Hewlett-Packard Model 7034A, X-Y plotter. Of the 30 jolts recorded for each condition, a representative sample of 15 curves were superimposed onto one graph. This graph revealed the spread of the data; i.e., the repeatability of the shock spectra. From this graph an average spectrum was constructed which was used as the typical shock environment for a given Jolt test condition.

Data Analysis

The analysis phase involved taking one test program objective at a time and evaluating both the time histories and shock spectra. These objectives were:

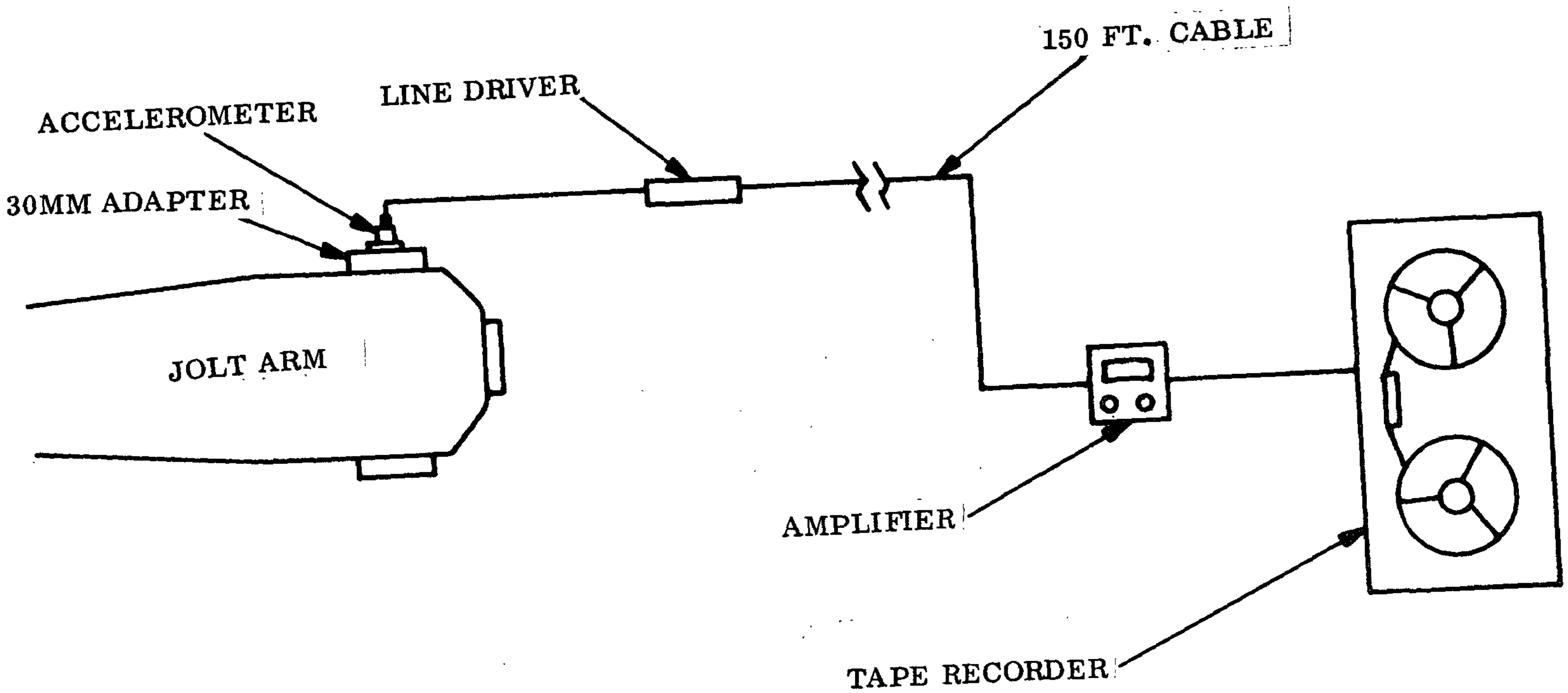


Figure 2. Jolt Test Data Acquisition System.

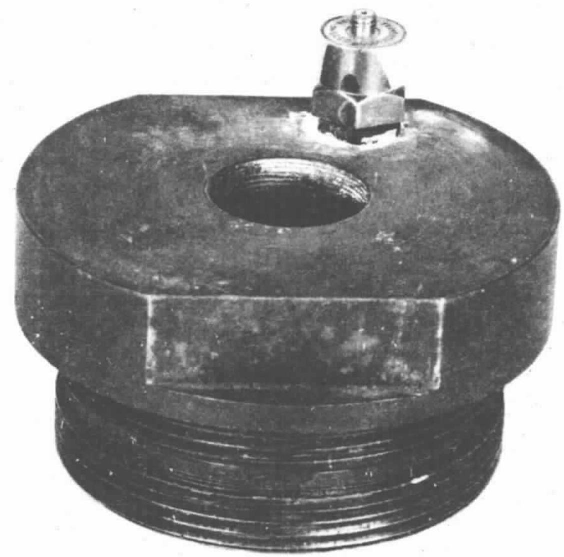


Figure 3. 30MM Fuze Adapter with Bonded Accelerometer.

Table 1. Jolt Test Program

Arm #	Orientation	Test load	#active Arms	Arm Material	Pad Material	Anvil Material
1	nose-up	9 lbs.	4	Wood	Leather	Wood
1	horizontal	"	4	"	"	"
1	nose-down	"	4	"	"	"
2	nose-up	"	4	"	"	"
3	nose-up	"	4	"	"	"
4	nose-up	"	4	"	"	"
1	nose-up	3 lbs.	4	"	"	"
1	nose-up	9 lbs.	1	"	"	"
1	horizontal	"	1	"	"	"
1	nose-down	"	1	"	"	"
1	nose-up	"	4	Nylon	"	"
1	nose-up	"	4	"	Polyurethane	"
1	"	"	4	"	"	Nylon
1	"	"	4	"	Leather	"
1	"	"	4	Wood	"	"
1	"	"	4	"	Polyurethane	"
1	"	"	4	"	"	Wood
1	horizontal	"	4	Nylon	Leather	"
1	"	"	4	"	Polyurethane	"
1	"	"	4	"	"	Nylon
1	"	"	4	"	Leather	"
1	"	"	4	Wood	"	"
1	"	"	4	"	Polyurethane	"
1	"	"	4	"	"	Wood

1. Determination of the existing environment. This was done by generating shock spectra for all 30 time histories in the "arm 1, nose-up, 4 arms active, 9 lb. test load" test condition. A statistical analysis was performed to generate a mean (u) and standard deviation (o). Figure C-1 shows the reduced spectrum curves for $\mu \pm 3\sigma$. Note: (figures designated c- are found in Appendix C). It was reasonable to assume that the correlation of spectra for different test conditions to the standard could be no closer than the spread which existed between 30 shocks of the same condition. That is, when comparing shock spectra, there were no uniform guidelines stating how much variation between curves was tolerable. An acceptable tolerance had to be defined. A minimum tolerance was naturally limited by the ability of the standard test condition to repeat itself; therefore, this minimum had to be defined as the $\mu \pm 3\sigma$ curves.

The maximum allowable tolerance presented a more difficult problem. The shock spectrum was item dependent. The resonances of the test item dictated which frequencies were more important than others, and hence, at which frequencies closer correlation of the spectra needed to exist. Those natural frequencies varied from one fuze to another, and therefore, this flexibility of applying excessive tolerances to unimportant frequencies was not available. As a result, the entire spectrum from 10 Hz. up to 10,000 Hz. had to be considered equally. The upshot was that the different Jolt environments were evaluated by visual inspection of how well the average spectra were enveloped by the $\mu \pm 3\sigma$ curves for the standard test condition. (The balance of this subproject "$\mu \pm 3\sigma$ curves" will refer to the standard shock spectrum environment). In looking at a typical oscillogram of the standard test condition (see Figure B-1), the following information was apparent. NOTE: (figures designated B- are found in Appendix B). The pulse had a peak acceleration of about 210 g's, and it approached a half-sine shape with about a 2 ms pulse width. These results closely agreed with MIL-STD-331.

2. Determination of the degree of standardization. This phase was broken into two parts. First, the degree of standardization on a given arm was evaluated and then the uniformity from one Jolt arm to another was assessed.

To evaluate the environments on a given arm the "fuze axis horizontal" and "nose-down" positions were compared to the standard. Figures B-1 and B-2 show the typical time histories for the "standard", "horizontal" and "down" positions. In the "horizontal" position the g-level was considerably higher, 390 vs. 210, and the pulse width was shorter, 1.7 vs. 2.0 ms. In the "nose-down" position, the g-level was lower, 160 vs. 210, and the pulse width was longer, 2.5 vs. 2.0 ms. For both conditions, the pulse shapes compared

favorably to the standard. Figure C-2 shows the "fuze axis horizontal", average shock spectrum and its relation to the $\mu \pm 3\sigma$ curves. The horizontal curve showed significantly higher responses throughout the frequency spectrum. This curve along with the time history indicated a considerable increase in the severity of the test environment. Figure C-3 relates the "nose-down", average shock spectrum to the $\mu \pm 3\sigma$ curves. For the majority of the spectrum, up to about 1500 Hz., the "nose-down" curve bordered on the $\mu - 3\sigma$ curve, while above this frequency, the acceleration values were somewhat lower. The shock spectrum together with the oscillogram showed that there was a slight undertest relative to the standard. In looking at data from all three positions on the same arm, it was apparent that the test item saw three different shock environments.

In assessing the uniformity of the shock environments from one arm to another, arm #4 in the "nose-up" position was compared to the standard. Figures B-3 and B-1 show the respective time histories. In comparing the "nose-up" positions the pulses were very similar in magnitude, pulse width and pulse shape. There was slightly more high frequency superimposed on the arm #4 pulse. Inspection of the shock spectrum (see Figure C-4) confirmed this analysis. The test curve fell well within the $\mu \pm 3\sigma$ envelop except in an area from about 2500 to 4000 Hz. This indicated that there was relatively good standardization between arms.

3. Determination of the effect of altering shock parameters. The first parameter investigated was varying the number of active arms. Figures B-1 and B-4 shows the oscillograms for the standard and arm #1, "nose-up", 1 arm active conditions. There was practically no difference between the pulses with regard to magnitude, pulse width and pulse shape. This was also evident in looking at the shock spectrum. (see Figure C-5). The entire curve fell within the standard envelop, and analysis indicated that the two test conditions produced identical shock environments.

The next investigation was concerned with the different jolts produced by changes in test loads. Figures B-1 and B-5 show the time histories of the standard and 3 lb. test load conditions. The smaller load resulted in a higher g-level, 260 vs. 210, a slightly shorter pulse width and about the same pulse shape. The higher g-level for the smaller load was predictable, and yet it still fell within acceptable tolerances of MIL-STD-331. The shock spectrum for this test condition is shown in Figure C-6. Up to 100 Hz. the curve fell within the $\mu \pm 3\sigma$ envelop. For the balance of the spectrum, the curve showed accelerations that were higher reflecting the increased g-level of the time history pulse. The largest differences between the standard and test conditions were found in the area from 500 to 1500 Hz. In this range the disparity of g-levels between the test curve and the M $\pm$ 30 curve was on the order of 30%.

The next three comparisons were concerned with the substitution of materials of the arm, pad and anvil.

Figures B-1 and B-6 show the time histories of the standard and the condition of nylon substituted for the wood arm. The peak g-levels and pulse widths were very similar. The only difference appeared to be a slight distortion to the nylon arm's pulse shape. While the standard appeared to approximate a half-sine, the nylon arm was tending to distort towards an initial peak sawtooth. That is, there was a sharper rise and a slower decay of the shock pulse. In looking at the shock spectrum, (Figure C-6), the test curve fell within the standard envelop for the majority of the spectrum. However, it was apparent that the test curve was shifted to the right in the envelop, an indication of the steeper front of the shock pulse.

Figures B-1 and B-7 show the oscillograms of the standard and the condition of polyurethane substituted for the leather pad. It was apparent that the environment had not been altered in replacing the pad.

Figures B-1 and B-8 show the time histories of the standard and the condition of nylon for the wood anvil. Again, there were no significant changes resulting from anvil substitution.

The last several evaluations covered a modified Jolt machine containing various combinations of substitute materials.

In the first test the arm and pad materials were both changed. Figures B-1 and B-9 show the oscillograms for the standard and modified conditions. The peak g-levels were about the same and the small variation in pulse widths were indicative of the arm materials. Figure C-7 shows the shock spectrum for this condition.

In the next test the wood arm and anvil were replaced with nylon. Figures B-1 and B-10 show the time histories for the standard and modified machine. In this instance, the g-level of the test condition was slightly higher than the standard, 230 vs. 210. The pulse width and pulse shape showed an apparent dependence on the arm material. Figure C-8 shows the respective shock spectrum.

Figures B-1 and B-11 show the time histories of the standard, and the change of the pad and anvil. In this case there was little change to the shock environment.

Finally, the arm, pad and anvil were all replaced with substitute materials. Comparison of Figures B-1 and B-12 showed a significant change in the time histories. The modified machine's g-level was lower than the standard,

180 vs. 210, and the pulse width and pulse shape were slightly distorted as in previous measurements with the nylon arm. Figure C-9 shows the shock spectrum which indicated the test curve bordered on the lower edge of the $\bar{\mu} - 3\sigma$ curve.

Results

Table 2 summarizes the time histories of all of the test conditions investigated and the results obtained.

Conclusions

The following conclusions have been reached concerning work done on the Jolt test subproject.

1. There is no one shock pulse associated with the Jolt machine that can completely describe the environment to which a fuze is subjected.

2. The shock depends primarily on the orientation of the fuze on the Jolt arm. This pulse will vary from 160 g's, 2.5 ms in "nose-down" to 390 g's, 1.7 ms in "fuze axis horizontal" for a total test load of 9 pounds (3 fuzes @ 3 lbs./Fuze).

3. The shock depends to a lesser extent on the weight of the test item. In the "nose-up" orientation a 9 lb. test load sees 210 g's, a 3 lb. test load experiences 260 g's.

4. The g-level is a function of the distance from the impact surface. This explains the disparity of results from different orientations. It has been found that the g-level imput will vary from one side of a fuze to the other, depending on how the fuze threads into the attaching socket, even in the "nose-up" orientation. The only acceptable reason for this is that some angular acceleration is developed when the arm impacts. This difference in g-level will increase with the increasing radial distance, from the measurement points on the overhanging sockets to the impact surface.

5. The shock pulse shape approximates a half-sine with a high frequency (on the order of 3000 to 4000 Hz.) superimposed over the main pulse.

6. The Jolt shock is independent of arm location. Arm #1, "nose-up", given the same shock as arm #4, "nose-up". However, this may not be true if the machine does not meet MIL-STD-331 test specifications.

7. The Jolt shock is independent of the number of active arms to the extent that the main pulse is not effected. There is a minor response on a given

Table 2. Jolt Test Time History Summary

Comparison	Peak g-level	Pulse width (ms.)	Comments on pulse shape
Standardization for a given arm			
Nose-up	210	2.0	all similar (approaching a half-sine)
Fuze axis horizontal	390	1.7	
Nose-down	160	2.5	
Standardization between arms			
Arm #1	210	2.0	
Arm #4	210	2.2	similar
Number of active arms			
4 arms	210	2.0	
1 arm	210	2.2	similar
Test load			
9 lbs.	210	2.0	
3 lbs.	260	1.9	similar
Arm material			
Wood	210	2.0	
Nylon	220	2.4	sharper rise slower decay (similar to an initial peak sawtooth)

Table 2. Jolt Test Time History Summary (Cont'd)

Comparison	Peak g-level	Pulse width (ms.)	Comments on pulse shape
Pad material			
Leather	210	2.0	
Polyurethane	210	2.2	similar
Anvil material			
Wood	210	2.0	
Nylon	200	2.2	similar
Arm & Pad			
Wood & Leather	210	2.0	
Nylon & Polyurethane	195	2.4	sharper rise slower decay
Arm & Anvil			
Wood & Wood	210	2.0	
Nylon & Nylon	230	2.4	sharper rise slower decay
Pad & Anvil			
Leather & Wood	210	2.0	
Polyurethane & Nylon	200	2.2	similar
Arm, Pad & Anvil			
Wood, Leather, Wood	210	2.0	
Nylon, Polyurethane, Nylon	180	2.7	sharper rise slower decay

active arm from the jolt of a neighboring active arm; however, this response is so small that it can be ignored.

8. There are four or more rebounds after the main pulse resulting in lower level shocks which, when compared to the main pulse, are not considered damaging to the test item. Therefore, the rebounds are not considered important in describing the damage potential of the Jolt machine. The first rebound occurs about 200 ms after the main pulse.

9. Under existing tolerances in MIL-STD-331 (200 to 270 g's), the 3 lb. loaded Jolt arm provides an acceptable shock pulse (260 g's). Since a load of 3 lbs. represents about the smallest test weight possible on the Jolt machine, it is concluded that dummy loads are not required when fewer than three test items for a given arm are available.

10. Shock spectra can and should be used when describing the Jolt shock. The "standard" environment must take into account the shock spectrum, because a jolt is not a simple shock pulse. The shock spectrum represents the Jolt machine's damage potential which is the main concern in designing a fuze to withstand the Jolt test.

11. Material substitution of the machine components is possible. Using certain combinations of alternate materials does not significantly change the Jolt shock environment, despite minor change to the pulse shape. The acceptable combinations of materials are as follows:

a. wood arm, leather pad, wood anvil (existing standard)
b. nylon arm, leather pad, wood anvil
c. nylon arm, polyurethane pad, wood anvil
d. wood arm, polyurethane pad, wood anvil
e. wood arm, leather pad, nylon anvil
f. wood arm, leather pad, nylon anvil

Note: Nylon and polyurethane can be procured more quickly than wood and leather.

12. Endurance testing has indicated that the substitute materials will wear better than the existing standard materials. In particular, a polyurethane pad not only wears better than leather, but after 300 hours of testing, it is impossible to estimate when the pad will ever require replacement. (See Appendix A).

13. Finally, the author concludes that testing on the existing Jolt machine is an economical, practical and convenient method for checking the safety and ruggedness of a test item.

Recommendations

The following recommendations are made concerning the Jolt test:

1. A minimum number of arms should be used when performing the test. It is not necessary to load up extra arms with dummy fuzes since the shock is independent of the number of active arms.

2. On the existing machine, it is recommended that material substitution of the components be permitted, allowing the use of a nylon arm and a polyurethane pad. This will facilitate the procurement of new Jolt arms and pads and it will provide for longer wear.

3. It is recommended that accelerometer monitoring of the machine be performed at least once a month on the "nose-up" position of every active Jolt arm. Measurements of the peak g-levels and pulse widths should be recorded along with the external test loads (including adapters and excluding the net weight of the arm).

4. Finally, it is recommended that the Jolt machine be redesigned. In its present form, the machine allows for too many parameters to effect the shock. This results in a poor degree of shock standardization throughout DOD and the contractor's test facilities. In any redesign, the important factor to consider is that one fuze should see the same shock as another throughout the test. This does not mean that different type fuzes should see the same shock. It is reasonable to expect that a heavier fuze will tend to experience lower level shocks than a lighter fuze in rough handling, and hence, the new test machine should be able to account for this. The machine must provide shocks that are test-item, weight-dependent.

There is an opinion that when the Jolt machine was originally designed there was never any intention of providing different shocks for the various fuze orientations. It was merely an accidental result of the design. Therefore, the redesigned machine should impart the shock through a point, on-line with the axis of the test item; that is, the impact surface should not be eccentric from the mounted fuze. If it is desired to shock in more than one direction, a vertical support fixture could be designed which would mount onto a horizontal plate providing the same input in any one of 4 transverse directions. Such a fixture is commonly used in vibration testing.

The basis for providing 4 arms on a shaft is to be able to jolt many fuzes at a time. The redesigned machine should also be able to do this. However, instead of using 4 arms, mount all the fuzes onto one plate and provide a simultaneous shock.

The redesign must also consider the large number of jolts in the specification (at present 1750 shocks in each of 3 directions) and be able to complete the test in the shortest time possible. This would necessitate either a reciprocating device, such as a cam driven shaft, or else an electrically controlled hydraulic machine.

Finally, the redesigned machine should provide a simple shock pulse, easily describable and easily repeatable throughout the fuze testing facilities. The shock pulse should be on the order of 225 g's, 2 ms, and the pulse shape should either be a half-sine or terminal peak sawtooth.

Implementation

Implementation of the recommendations has been initiated as follows:

1. MIL-STD-331, Test 101 was revised to allow for using fewer than 4 arms when performing the Jolt test. While not written explicitly into the revised test, this is understood by the omission of any requirement, on the number of active arms. The revision was incorporated into MIL-STD-331, Notice 7, dated May 1, 1973.

2. At the January 1975 meeting of the Fuze Engineering Standardization (FES) Working Group, tentative approval was given for allowing the use of nylon and polyurethane as alternate materials for the Jolt arm and pad. The recommendation was given final approval after confirmation that there were no detrimental effects to polyurethane after long term exposure to high humidity. The confirmation given was based on the results of subjecting samples of polyurethane to a Humidity test, Method #507, Procedure 1 of MIL-STD-810B. This revision is being incorporated into MIL-STD 331A, which is awaiting publishing. The rationale presented to the FES at the January 1975 meeting is shown in Figure 4. Some difficulty was encountered in specifying polyurethane. There was no federal specification on this material having the same properties as the tested material. Accordingly, a specification control drawing No. 11820403, "Polyurethane Sheet, Hard", was made. This drawing, together with the material specification for the arm, "Nylon Type 6, Cast", was referenced in the revised list of materials for the Jolt machine (Drawing 81-3-30A).

In addition, a paragraph was written which appears in Section 6 of the Jolt test reflecting the rationale behind the revision. Finally, this report is to be referenced in the bibliography, Section 7, of the revised MIL-STD.

3. The FES is presently considering the recommendation for redesigning the machine. An attempt is being made in the interim to define an alternate Jolt test, using a commercial machine to provide a simple pulse input.

MIL-STD-331

TEST 101.1

JOLT

(This is not a part of the test method)

RATIONALE

This revision to the Jolt test (Test 101.1) is to substitute cast nylon for the wood arm and polyurethane 75D hardness for the leather pad. This revision is proposed for the following reasons:

a. The substitute materials provide a similar test environment.

b. The substitute materials will be more uniform and more consistent with time, from piece to piece and from agency to agency, thus achieving more uniform testing of fuzes.

c. The nylon can be cast to Jolt arm shape, thus eliminating costly labor in machining the wood arm.

d. Experience has shown that the procurement cycle for the substitute materials is significantly shorter than that for wood and leather.

Page changes for Test 101.1:

1. page 1, para. 2.1, replace with "This test-------------------- onto a polyurethane * padded wooden anvil."

2. page 1, para. 4.1, 4th sentence; replace with "The free ends ----- ----------onto a polyurethane * padded wooden anvil."

3. page 2, para. 5.1.b; replace "wood" with "cast nylon*".

4. page 2, para. 5.1.d; replace "leather" with "polyurethane*".

5. revise drawings 81-3-30A, -31, -32 to change arm material from "oak" to "cast nylon" and to change pad material from "leather" to "polyurethane 75D hardness (shore)". Add note: "Existing stocks of oak arms and leather pads may be used until depleted."

*For future procurements, the arms shall be made of cast nylon and the pad shall be made of polyurethane 75D hardness; however, existing stocks of wooden arms and leather pads may be used until depleted.

Figure 4. Rationale for Revising MIL-STD-331 Jolt Test

JUMBLE TEST

Background

The Jumble test like the Jolt test is used as a safety and ruggedness test. The fundamental difference between the two is that in the Jolt test the fuze is subjected to a shock as a result of the Jolt arm impacting, while in the Jumble test impact occurs directly on the fuze making contact with the wood-lined steel Jumble box. The Jumble test was originally designed to simulate the environment that a loose fuze might see while being transported on an Army caisson over rough terrain. However, today it is merely used as a measure of ruggedness and is not necessarily indicative of the existing loose fuze transportation environment.

An investigation of the Jumble test, No. 102 of MIL-STD-331 was performed to determine if it was possible to substitute materials for the maple wood Jumble box liner. Recently, there has been some difficulty in procuring maple. Two plastics, polyurethane and polyethylene, were evaluated as possible substitutes. Because of the difficulty in making measurements inside the Jumble box, a pendulum test was developed in-house. In this simulation of the Jumble test, accelerometer measurements were made on fuze, as it impacted on the three liner materials. Evaluations were then made on the shock environments to determine how closely the plastics compared to wood. In addition, wear tests were performed to determine whether the plastics wore better than maple. To better understand the problem associated with the Jumble box liner, a brief description of the machine and test procedures are presented.

Description of the Jumble Machine

The Jumble machine consists of a wood-lined steel box which is rotated about a support shaft at 30 RPM (See Figure 5). The size of the box is determined from the largest dimension of the fuze. Table 3 lists the proper box dimensions.

Table 3. Jumble Box Dimensions

Fuze Max. Dimension	Test Box Size (Inner Dimensions)	Test Box Designation
5" or less	17.5" x 12.5" x 6.5"	A
5" to 10"	21.5" x 15.5" x 11.5"	B
10" to 15"	25.5" x 19.5" x 17.5"	C

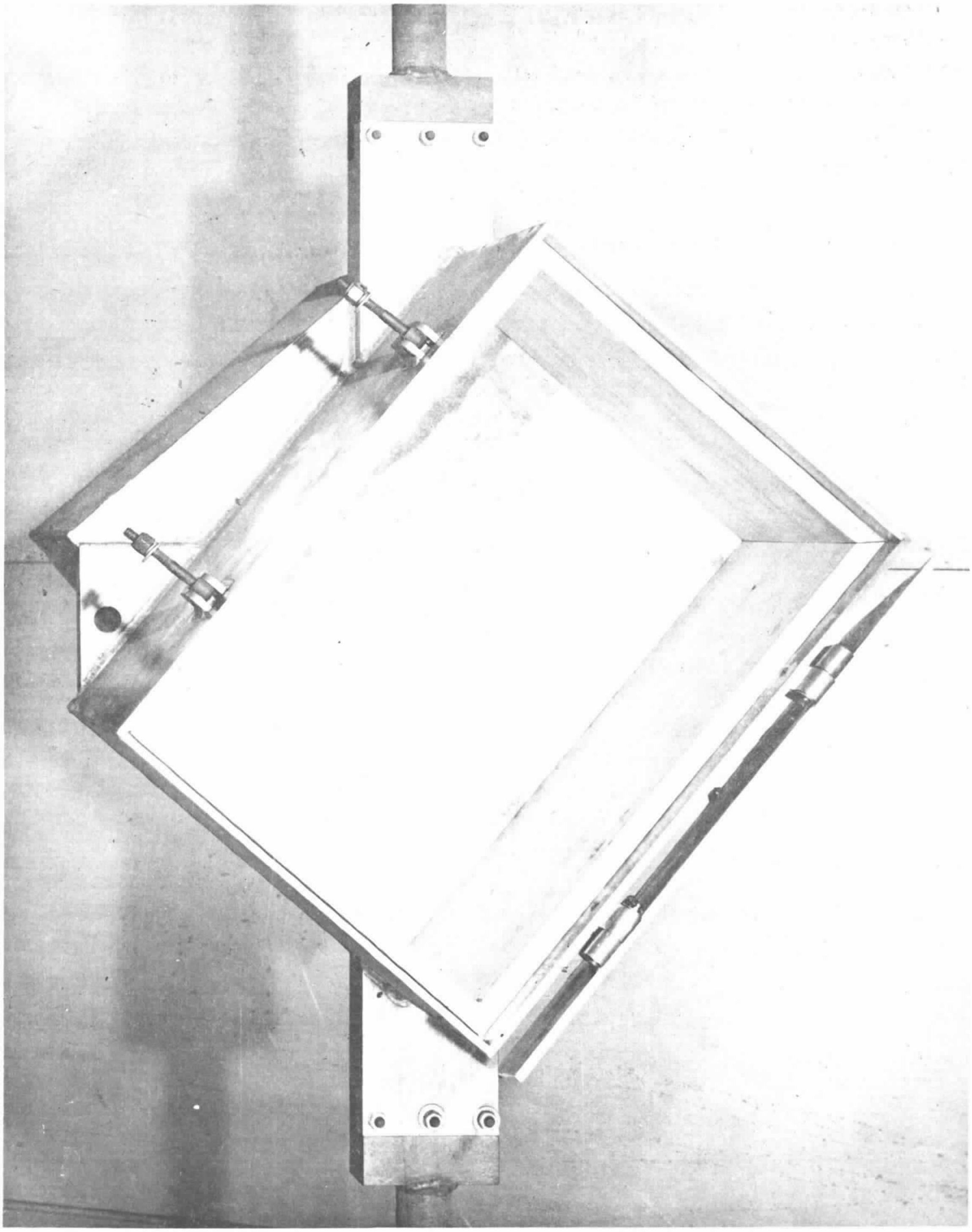


Figure 5. MIL-STD-331 Jumble Box; shown with top section removed.

The liner is made up of six sections of material. In this report, the six sections are designated as "top", "bottom", "left end", "right end", "front" and "back". These 3/4" thick sections fit together to form a rectangular box. As the test item is rotated inside the box, the liner wears from repeated impacts. When the thickness of any section of the liner is reduced to 1/4", the liner is replaced.

Jumble Test Procedure

After choosing the proper size box for a given fuze, the wood (hard maple) liner is inspected. A thickness of 1/4" minimum is required. After the machine is confirmed to be in good operation condition, a bare, unprotected fuze is placed inside the box which is then rotated, jumbling the fuze for a period of two hours through 3600 revolutions. At the conclusion of the test, an inspection is made to assess the structural integrity and to determine whether the fuze, while not necessarily functional, is safe to handle and transport.

Problem Area

A major difficulty in performing the Jumble test has been found in the procurement of new maple wood liners for the box. At present, it takes an intolerably long time to acquire new liners once an order is placed. This is a result of a scarcity of material meeting test drawing specifications. With an expected test life of possibly less than 60 hours (as will be shown in the Wear test) the problem is enhanced. A question of standardization also arises, since wood tends to have physical properties as a function of grain cut, and different test facilities obtain wood from different lots. Therefore, how can standardization be insured from one test facility to another?

The objective of this subproject was to find a material which not only gave the same dynamic environment as already existed in the Jumble box, but was also easier to procure, wore better, and was more uniform from piece to piece.

Pendulum Test

The Pendulum test was developed in-house in an attempt to simulate the dynamic environment of the Jumble test. Since the Jumble box was enclosed and rotated about a shaft, hard wire shock measurements appeared to be unnecessarily difficult to perform. Moreover, no telemetry systems were known to be available which could withstand the severe shock environment and still perform satisfactorily. Accordingly, a pendulum test was formulated, based on conjecture of what happened inside the box. The following observations were made.

First, the fuze was struck against the liner in different orientations. Sometimes there was direct impact of the nose, base, or side of the fuze. Other times, the fuze hit at some angle. The fuze also rolled inside the box. Therefore, as the box rotated there were different distances from which the fuze impacted the liner. It was also evident that after a certain time the liner wore from an initial thickness of 3/4" down to 1/4" at which time the test specification required liner replacement. In designing an adequate test, it was necessary to consider as many parameters as practical to insure substitute material's conformability to maple wood's dynamic response.

The test consisted of displacing a pendulum with a fuze acting as the supported mass, a known distance from the vertical and allowing the system to swing into liner material mounted on a steel channel (see Figure 6). The lower end of the pendulum shaft was threaded for attachment of a fuze, which was also tapped in six locations to allow for hard mounting of an accelerometer. The shaft was designed for flexibility so that the accelerometer measured only the fuze shock environment. If the shaft had been rigid, much energy from the impact of the fuze on the liner would have been dissipated up through the arm and fulcrum, resulting in a distorted view of the shock environment. Sections 3" x 5" were cut from stocks of liner materials and were fastened to the 1/4" thick steel channel by means of 4 bolts, one at each corner of the section. This simulated the effect of a lined-steel jumble box. In this test an XM571 fuze was used whose length was about 6" and which weighed approximately 1 1/2 pounds. The data acquisition system, as indicated in Figure 6, consisted of: a shock accelerometer, signal conditioner, and tape recorder. The overall system frequency response was 10,000 Hz limited by the 30 IPS tape recorder speed. Fifteen shocks were recorded for each test condition to insure a sufficient sample for analysis. A test condition was defined as a liner material with a certain thickness, in a given orientation at a specific drop height (distance from vertical); e.g., wood 3/4", nose flat, 5". The distance from vertical was the shortest distance of the displaced fuze to the liner material as measured by a ruler. Table 4 lists the conditions investigated in the Pendulum test program.

Data Analysis

The philosophy behind the data analysis was based on the following premise: if two materials tended to produce similar dynamic environments for identical test conditions, then those materials would tend to produce similar Jumble environments provided that the test conditions were judiciously chosen to represent those found in a Jumble test. Therefore, the object of this analysis was to determine the extent of the similarity of dynamic environments. The shock spectrum method was chosen to assess that similarity. The data was analyzed by visual comparison of average spectra of the various conditions. The four parameters of liner material, liner thickness, fuze impact

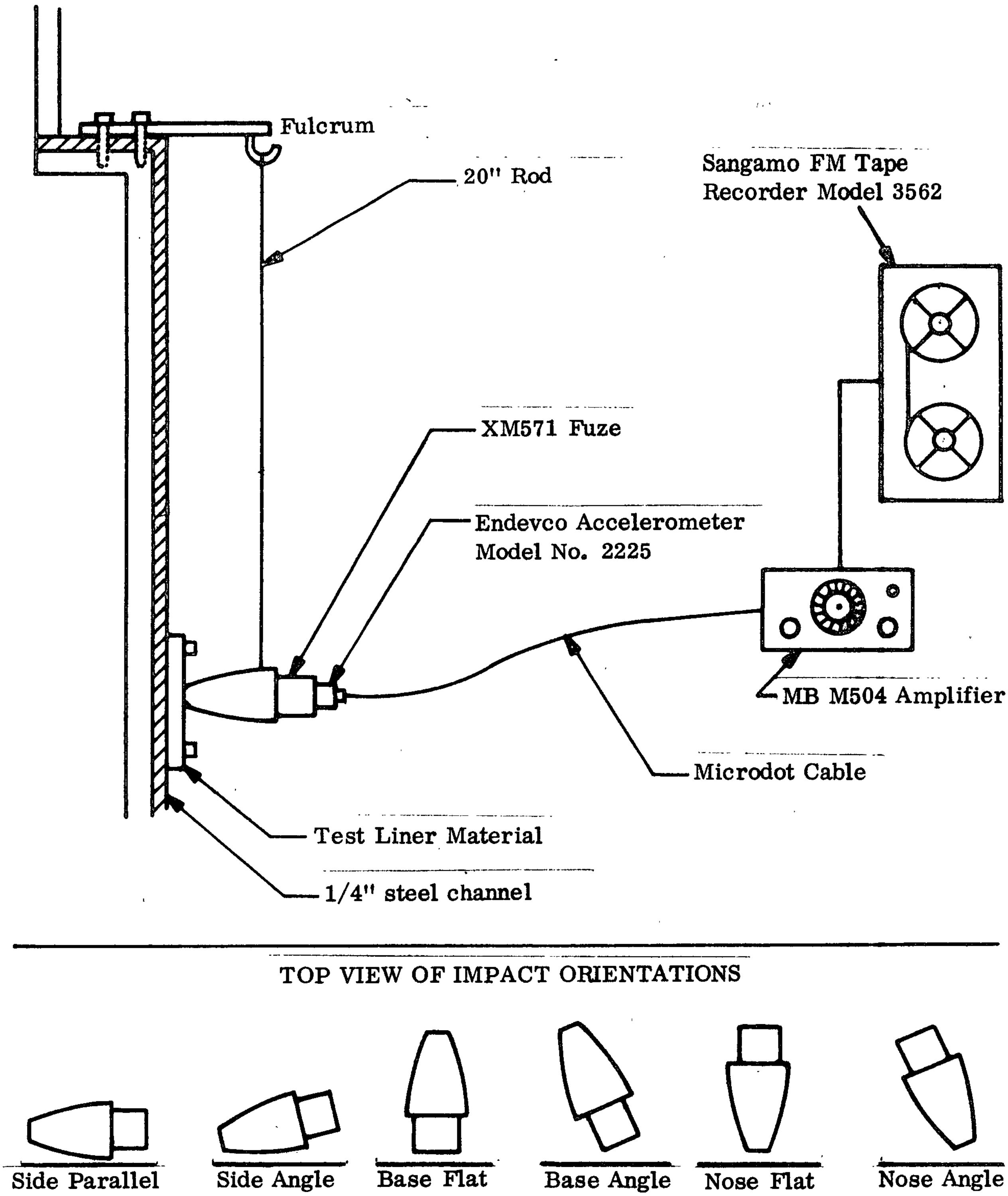


Figure 6. Pendulum Test Set-up and Instrumentation.

Table 4. Pendulum Test Program

liner material	liner thickness	impact orientation	drop height
wood	3/4"	nose flat	5"
"	"	"	10"
"	"	nose angle 10^o	5"
"	1/4"	nose flat	5"
"	"	"	10"
"	"	nose angle 10^o	5"
PU	3/4"	nose flat	5"
"	"	"	10"
"	"	nose angle 10^o	5"
"	1/4"	nose flat	5"
"	"	"	10"
"	"	nose angle 10^o	5"
PE	3/4"	nose flat	5"
"	"	"	10"
"	"	nose angle 10^o	5"
"	1/4"	nose flat	5"
"	"	"	10"
"	"	nose angle 10^o	5"

Wood = maple wood
PU = polyurethane
PE = polyethylene

orientation and drop height were investigated individually. (Note: Shock spectra are shown in Appendix D, and a sample of Pendulum test time histories are presented in Appendix E).

1. Liner Material. Average shock spectra from six test conditions were available for comparing the three liner materials. Table 5 summarizes this parameter investigation. In most instances, the spectra were very similar up to 1000 Hz. From this frequency extending to 10,000 Hz, wood maintained a larger response than either polyurethane (PU) or polyethylene (PE). The greatest differences occurred in the "nose-angle" orientation and the closest correlation was found in 10" drop heights.

2. Liner Thickness. Nine test conditions were used in comparing two liner thicknesses 3/4" vs. 1/4". Table 6 summarizes the results of this investigation. In most conditions the thinner liner resulted in lower level response spectra. Wood showed the best uniformity, while PU & PE showed spectra whose shapes were similar to wood, but on the average, had about 20 percent lower level response levels. The largest differences were in frequencies above 3000 Hz.

3. Fuze Impact Orientation. From six test conditions it was obvious that a nose angle impact orientation resulted in a lower level shock. The summary of results is shown in Table 7. The peak g-level is about 300 for nose flat vs. 100 for nose angle for a 5" drop height.

4. Drop Height. Six test conditions were used in comparing 10" vs. 5" drop height. Table 8 summarizes this analysis. Doubling the drop height resulted in doubling the response in the lower portion of the average spectra. The cut-off frequencies, beyond which the differences in responses significantly exceeded 100 percent, were for wood, 1500 Hz; 3/4" PU, 1500 Hz; 3/4" PE, 2000 Hz; the thinner sections of PU and PE had cut-off frequencies of 400 Hz and 800 Hz respectively.

In comparing the average spectra, consideration was given to the preliminary graphs containing the superimposed spectra of 15 shocks per condition. A review of those graphs indicated large variations of response spectra from one shock to another for a given test. Therefore, a 20% variation between average spectra was not considered significantly large. In fact, variations of greater than 50% were not uncommon! This was primarily due to the release technique used in the Pendulum test. The greater differences appeared in the 5" drop heights, where differences in release positioning had the greatest effect. When the drop height was

raised to 10" more similar spectra were obtained. Also, at attempting to test in a "nose-angle" orientation, some difficulty was encountered in reproducing similar shock spectra. This was the result of a change in the 10^{o} angle orientation upon repeated impacts. Friction between the fuze and the threaded pendulum shaft was the only force maintaining the orientation. The impact shock was probably severe enough to change that angle after repeated impacts resulting in different frequency response curves.

In summary, both polyurethane and polyethylene produced similar dynamic environments to that of wood under the same test conditions. While variations existed between the average spectra, the differences were not considered significant enough to eliminate PU and PE from further consideration as possible substitute materials for Jumble box liners.

Wear Test

The two physical requirements on the potential substitute materials for the Jumble box liner included a similar dynamic environment and better wear characteristics. Having found that polyurethane and polyethylene met the first of the two requirements, the next step was to compare the substitute materials against the maple wood in a wear test. First "A" size Jumble box liners (see Table 3) were made from stocks of maple, polyurethane and polyethylene. A Jumble test was then run for a period of 90 hours for each liner material. That length of time corresponded to 45 MIL-STD-331 Jumble tests. A dummy MT M565 fuze was used as a test item. At the start of each test run and after every six hours of operation, the six sections of material, which comprised the liner, were removed from the box and weighed. At the conclusion of tests, the wear rates for each material were evaluated by comparing the weight losses. To maintain uniformity the M565 test item was changed at the start of each test when the liner material was changed. This was done because the sharp corners of the fuze tended to dull after many hours of impacts.

Table 9 lists the before and after measured weights for each liner material in the 90 hour test. These weights are broken down into each of the six sections, and weight loss is given in both pounds and per cent. Figure 7 is the corresponding graph showing the weight loss in per cent for the three materials during the 90 hour test.

In looking at the results of the wear test, it was evident that wood wore more than polyurethane, and polyurethane wore more than polyethylene. The differences were such that a wood liner would require replacement twice as often as polyurethane and about 2-1/2 times as often as polyethylene.

Table 5. Pendulum Test Material Comparison

TEST CONDITION			MATERIAL		
liner thickness	impact orientation	drop height	Maple wood	Polyurethane	Polyethylene
3/4"	nose flat	10"	standard	similar spectrum	similar spectrum
3/4"	nose flat	5"	"	lower response above 1500 Hz	similar spectrum
3/4"	nose angle	5"	"	lower response above 1500 Hz	lower response above 300 Hz
1/4"	nose angle	5"	"	lower response	lower response above 1000 Hz
1/4"	nose flat	10"	"	lower response above 2000 Hz	lower response above 2000 Hz
1/4"	nose flat	5"	"	lower response above 300 Hz	lower response above 1000 Hz

Table 6. Pendulum Test Liner Thickness Comparison

TEST CONDITION			LINER THICKNESS	
liner material	impact orientation	drop height	3/4"	1/4"
Wood	nose flat	10"	Standard	similar spectrum
Wood	nose flat	5"	"	lower response
Wood	nose angle	5"	"	similar spectrum
PU	nose flat	10"	"	lower response above 3000 Hz
PU	nose flat	5"	"	lower response
PU	nose angle	5"	"	lower response
PE	nose flat	10"	"	lower response above 3000 Hz
PE	nose flat	5"	"	lower response
PE	nose angle	5"	"	higher response above 3000 Hz

note: wood = maple
PU = polyurethane
PE = polyethylene

Table 7. Pendulum Test Fuze Impact Orientation Comparison

TEST CONDITION			FUZE IMPACT ORIENTATION	
liner material	liner thickness	drop height	nose flat	nose angle
Wood	3/4"	5"	standard	significantly lower response above 300 Hz
Wood	1/4"	5"	"	"
PU	3/4"	5"	"	"
PU	1/4"	5"	"	"
PE	3/4"	5"	"	"
PE	1/4"	5"	"	"

Note: Wood = maple
PU = polyurethane
PE = polyethylene

Table 8. Pendulum Test Drop Height Comparison

TEST CONDITION			DROP HEIGHT	
liner material	liner thickness	impact orientation	5"	10"
Wood	3/4"	nose flat	Standard	twice the response under 1500 Hz; Significantly larger response above
Wood	1/4"	nose flat	"	"
PE	3/4"	nose flat	"	twice the response under 2000 Hz; significantly larger response above
PE	1/4"	nose flat	"	twice the response to 800 Hz; significantly larger response above
PU	3/4"	nose flat	"	twice the response to 1500 Hz; significantly larger response above
PU	1/4"	nose flat	"	twice the response to 400 Hz; significantly larger response above

Note: wood = maple
P U = polyurethane
PE = polyethylene

Table 9. Jumble Liner Wear Test #1

material	liner section	Weights (lbs.) initial	after 90 hours	change	per cent change	relative change
wood	bottom	4.38	4.28	0.10	2.28	
	right end	1.14	1.05	0.09	7.89	
	left end	1.15	1.09	0.06	5.22	100/100
	front	1.60	1.45	0.15	9.38	
	back	1.60	1.48	0.12	7.50	
	top	4.27	4.18	0.09	2.11	
		14.14	13.53	0.61	4.31	Total
PU	bottom	7.48	7.36	0.12	1.60	
	right end	1.97	1.92	0.05	2.54	
	left end	1.98	1.91	0.07	3.54	55/100
	front	2.83	2.70	0.13	4.59	
	back	2.85	2.75	0.10	3.51	
	top	7.43	7.32	0.11	1.48	
		24.54	23.96	0.58	2.36	Total
PE	bottom	5.45	5.41	0.04	0.73	
	right end	1.44	1.39	0.05	3.47	
	left end	1.45	1.39	0.06	4.14	43/100
	front	2.05	1.98	0.07	3.41	
	back	2.01	1.95	0.06	2.99	
	top	5.40	5.35	0.05	0.93	
		17.80	17.47	0.33	1.85	Total

Wood = maple
PU = polyurethane
PE = polyethylene

JUMBLE LINER WEAR TEST #1

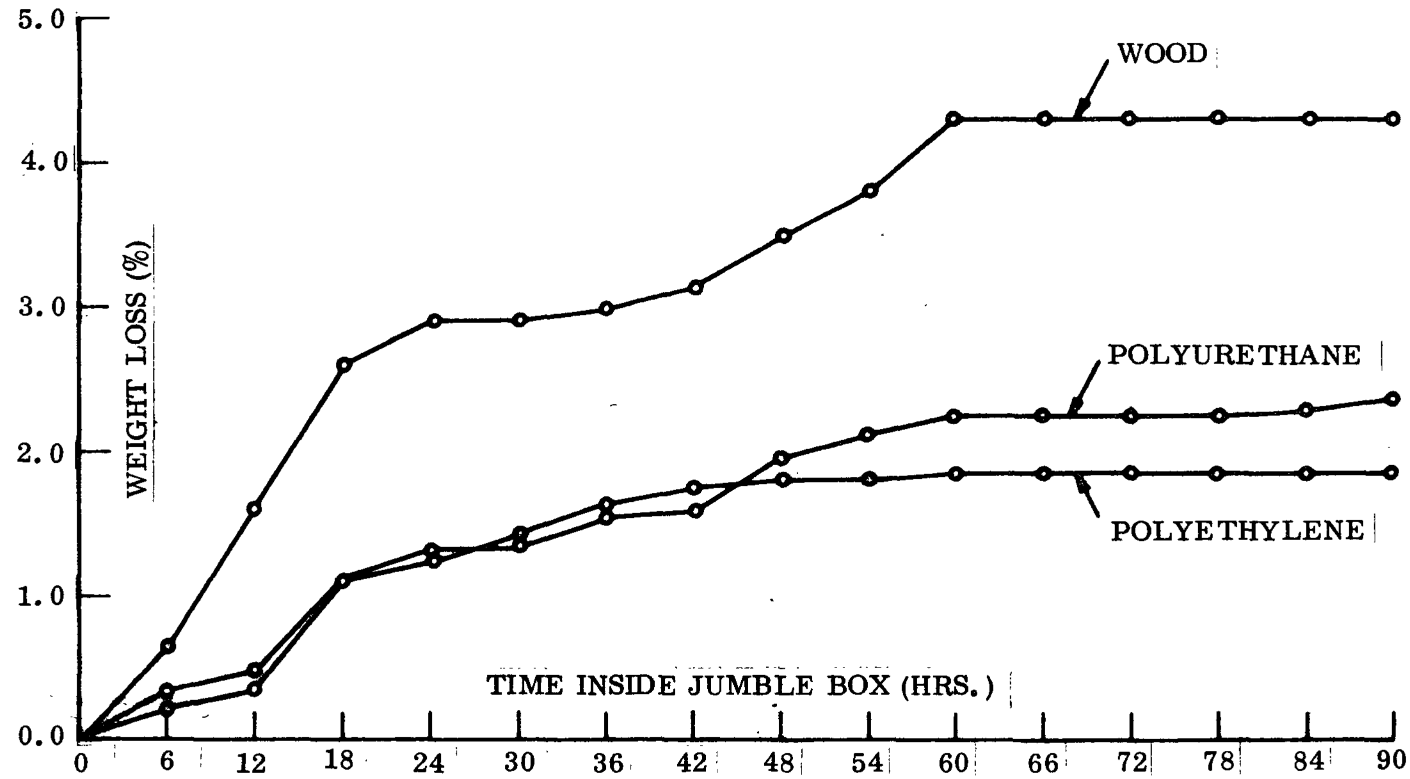


Figure 7. Jumble Liner Wear Test #1

A question arose after inspection of the worn Jumble liners. It appeared from looking at the depth of the penetrations in the worn areas that polyurethane was wearing more and polyethylene less that the weight losses indicated. (see Figure 8). At that time it was not certain whether or not the material density was changing in the area of the penetrations, from the repeated pounding of the test item. That is, in looking at weight loss to evaluate the wear of a material it was assumed that the density was uniform. If so, the change in weight corresponded to the change in thickness of the liner. However, if the density were changing in the areas of penetration, then it was possible that the material was being compressed rather than being worn away. If that were true, then it was also possible that a test liner might have large depths of penetration without significant weight loss. That could explain why polyurethane appeared to wear more than the weight loss indicated.

Therefore, a second test was developed to evaluate the wear of the liners based on the change in the liner thickness. This test involved spreading fine sand over the surfaces of the worn liners until there was a uniform 3/4" thickness. Therefore, wherever there were penetrations, the sand now replaced the volume of material worn away. The amount of sand required to fill the holes was then determined in the following manner.

The liner was turned upside down on a sheet of paper so that the amount of sand remaining after smoothing to a uniform thickness fell onto the sheet. The sand on the sheet of paper was then placed into a 25 ml. pharmaceutical graduate, and the volume of sand was measured. This process was repeated three times for each section of liner material to insure that the measurement process was accurate. The average of these three measurements was then used as a basis for evaluating the wear of the liner. Thus, the change in liner thickness was evaluated. That was really the main purpose in performing the wear test, because the specification required liner replacement, which was based not on weight loss of material, but on change of thickness.

Table 10 lists the measured volumes of sand in this second wear test. In comparing these results, wood wore more than polyurethane, and polyurethane wore more than polyethylene. In this second wear test the data corresponded more closely to the visual inspection. Polyurethane wore 40 percent less than wood, and polyethylene wore 65 percent less that wood.

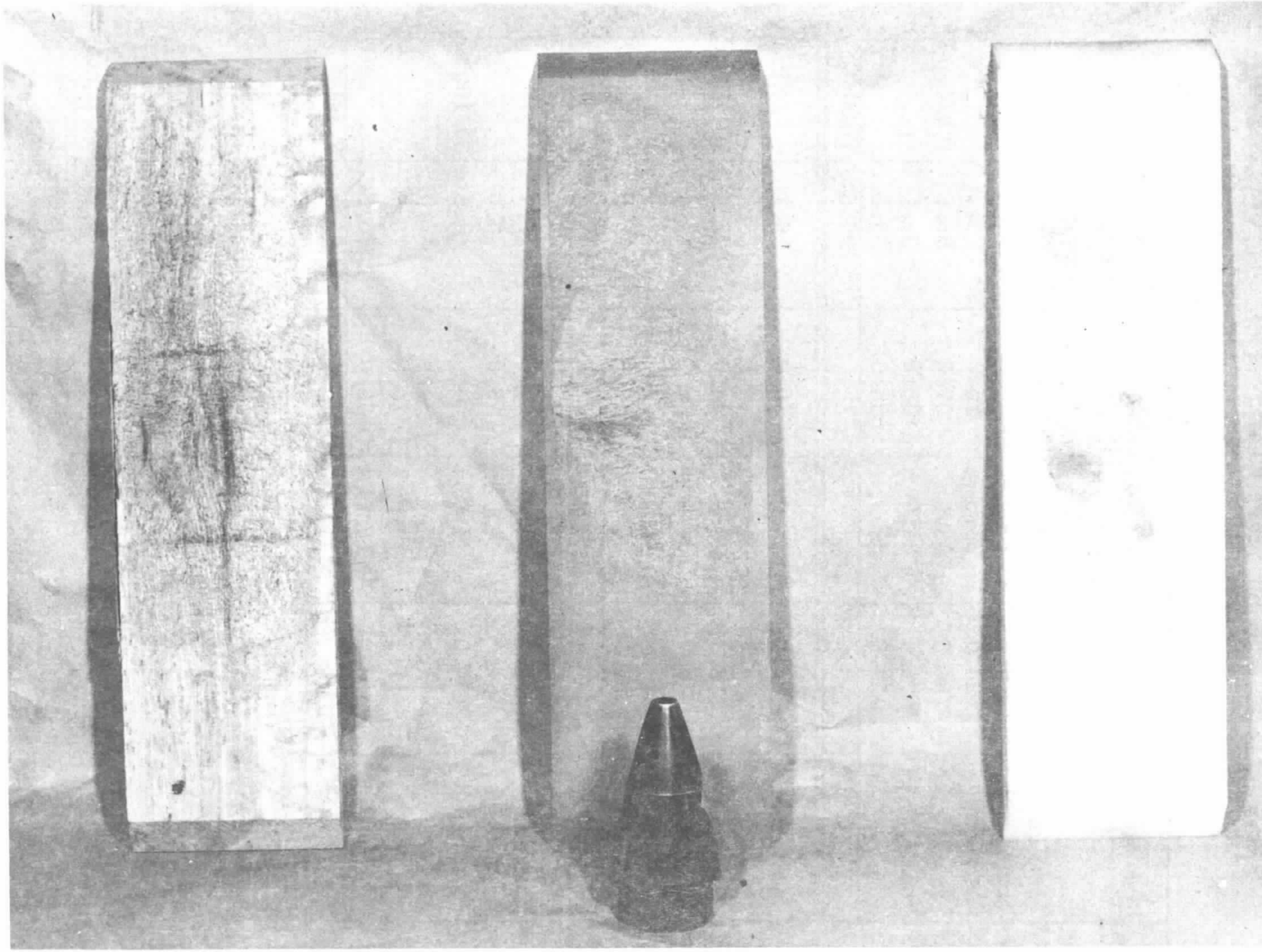
Conclusions

The following conclusions were made concerning the Jumble test subproject:

1. Polyurethane, polyethylene and wood produce similar dynamic environments based on shock spectra and time histories from the Pendulum test.

Table 10. Jumble Liner Wear Test #2

material	section	volume of sand displacing worn liner (m)				
		1st	2nd	3rd	average	
wood	bottom	19.5	23.0	21.5	21.3	
	right end	20.5	20.5	20.5	20.5	
	left end	24.0	23.5	25.0	24.2	
	front	54.5	58.0	57.0	56.5	100/100
	back	34.0	34.0	36.0	34.7	
	top	31.0	38.0	34.0	33.3	
					190.5	Total
PU	bottom	31.0	28.0	30.0	29.7	
	right end	3.5	4.5	4.0	4.0	
	left end	3.5	3.0	4.0	3.5	60/100
	front	34.0	30.0	30.0	31.3	
	back	12.0	10.5	13.0	11.8	
	top	34.0	35.0	36.0	35.0	
					115.3	Total
PE	bottom	19.0	19.0	21.0	19.7	
	right end	4.0	4.5	5.0	4.0	
	left end	4.0	4.0	4.0	4.5	35/100
	front	11.5	12.0	11.0	11.5	
	back	11.5	10.0	10.5	10.7	
	top	18.0	16.5	16.0	16.8	
					67.2	Total



Note: After 90 hours of jumble; also shown is the XM565 test item.

Figure 8. Sections of Worn Jumble Box Liners

2. Wood wears about 3 times as fast as polyethylene and slightly less than 2 times as fast as polyurethane. After about 60 hours of testing there is very little liner wear.

3. Polyurethane and polyethylene have been procured more quickly than maple wood.

Recommendations

Based on the above conclusions the following recommendations are made:

1. Polyethylene should be an allowable substitute material for the existing maple wood Jumble box liner.

2. A telemetering system should be developed for use as a shock environment measuring device inside the Jumble box.

3. Since the Jumble box produces greater accelerations than the Jolt machine (due to the direct impacts), a study should be undertaken to determine if the Jolt test is superfluous. Experience has shown that most failures occur in the Jumble test.

Implementation

Approval for permitting polyethylene for wood as an alternate Jumble box liner material was given at the January 1975 meeting of the Fuze Engineering Standardization (FES) Working Group. The approval will be implemented by a revision to the Jumble test in the soon to be published MIL-STD-331A. The rationale presented to the FES at the January 1975 meeting is shown in Figure 9. There was a problem in specifying polyethylene because there existed no federal specification on this material having the same properties as the tested material. Therefore, a specification control drawing No. 11820404, "Polyethylene Sheet, High Molecular Weight", was made. This drawing will be referenced in the revised list of materials for the Jumble box (drawing 81-3-35A). Also, a paragraph was written which will appear in Section 6 of the Jumble Test which reflects the rationale behind the revision. Lastly, this report will be referenced in the bibliography, Section 7.

TEST 102.1

JUMBLE

(This is not a part of the test method.)

RATIONALE

This revision to the Jumble test (Test 102.1) is to substitute polyethylene (HMW 1900 TM) for the maple wood liner. This revision is proposed for the following reasons:

a. Polyethylene provides a similar test environment.

b. Polyethylene will be more uniform and more consistent with time, from piece to piece and from agency to agency, thus achieving more uniform testing of fuzes.

c. Experience has shown that the procurement cycle for polyethylene is significantly shorter than that for wood.

Page changes for Test 102.1:

1. page 1, para. 2.1, 1st sentence; replace with "This test ------------- closed, polyethylene-lined* metal box."

2. page 1, para 4, 2nd sentence; replace with "This equipment consists of 3 sizes of polyethylene*-lined metal boxes and ----------."

3. page 2, para 5.2, 1st line; replace "wood" with "polyethylene".

4. revise drawings 1386-C13 through 1386-C17 to change material of various liner parts to "polyethylene (HMW 1900 TM)." Add note: "Existing stocks of maple wood liners may be used until depleted."

*For future procurements of box liners, the liners shall be made of polyethylene (HMW 1900 TM); however, existing stocks of maple wood liners may be used until depleted.

Figure 9. Rationale for Revising MIL-STD-331 Jumble test

FIVE FOOT AND FORTY FOOT DROP TEST MONITORING SYSTEM

Introduction

An investigation was made into the Five Foot Drop (No. 111) and Forty Foot Drop (No. 103) tests in MIL-STD-331 to devise a technique for verifying projectile impact angles. This subproject describes the problems encountered in attempting to develop a monitoring system which could be standardized throughout fuze test facilities. A system using a ballistic screen, a time delay unit, and two solenoid actuated cameras was procured and tested in the Frankford Arsenal Drop Tower. A special analysis scheme developed by the Pitman-Dunn Laboratories was used in conjunction with the monitoring system. Together they provided immediate measurements of projectile impace angles. Photographs of impacts in a Five Foot Drop test are presented which demonstrate the successful operation of the system.

Description of the Test Method

In the Drop tests, a test item is allowed to free fall from a prescribed height onto a steel plate which is mounted on a concrete foundation. The test item consists of a loaded, unarmed fuze that is assembled into an inert-loaded projectile, bomb or warhead. The restriction on the impact area is that it is sufficiently large, and it is strong enough to contain a rebounding projectile. For each test lot, there are sets of five drops, corresponding to five different impact orientations, and no fuze is dropped more than once. That is, for each drop the same projectile can be used, if it hasn't been overly damaged from previous drops, but an undropped fuze must be assembled to the projectile.

The Drop Test Facility at Frankford Arsenal

The facility can be thought of as being composed of three distinct areas: the tower, the impact area and control room. The structural steel tower is approximately 50 feet high. It is designed to provide drops from up to 40 feet (see Figure 10). The impact surface consists of a 4" thick steel plate mounted on a concrete foundation. The impact area is enclosed by wood-lined, steel walls, with a ceiling about 7 feet above the impact surface to contain a rebounding projectile. The control room has one panel which controls the entire drop facility. Using this panel, the hoist can raise or lower the test item to any desired height, when measured by a footage counter. A quick release mechanism on the hoist is also activated from this control panel. Safety features have been incorporated into the facility to prevent accidents. For example, if the doors leading into the impact area are open, the quick-release triggering mechanism on the hoist is deactivated. The drop facility also contains a partially guided system which functions from 40', down to about 14'.

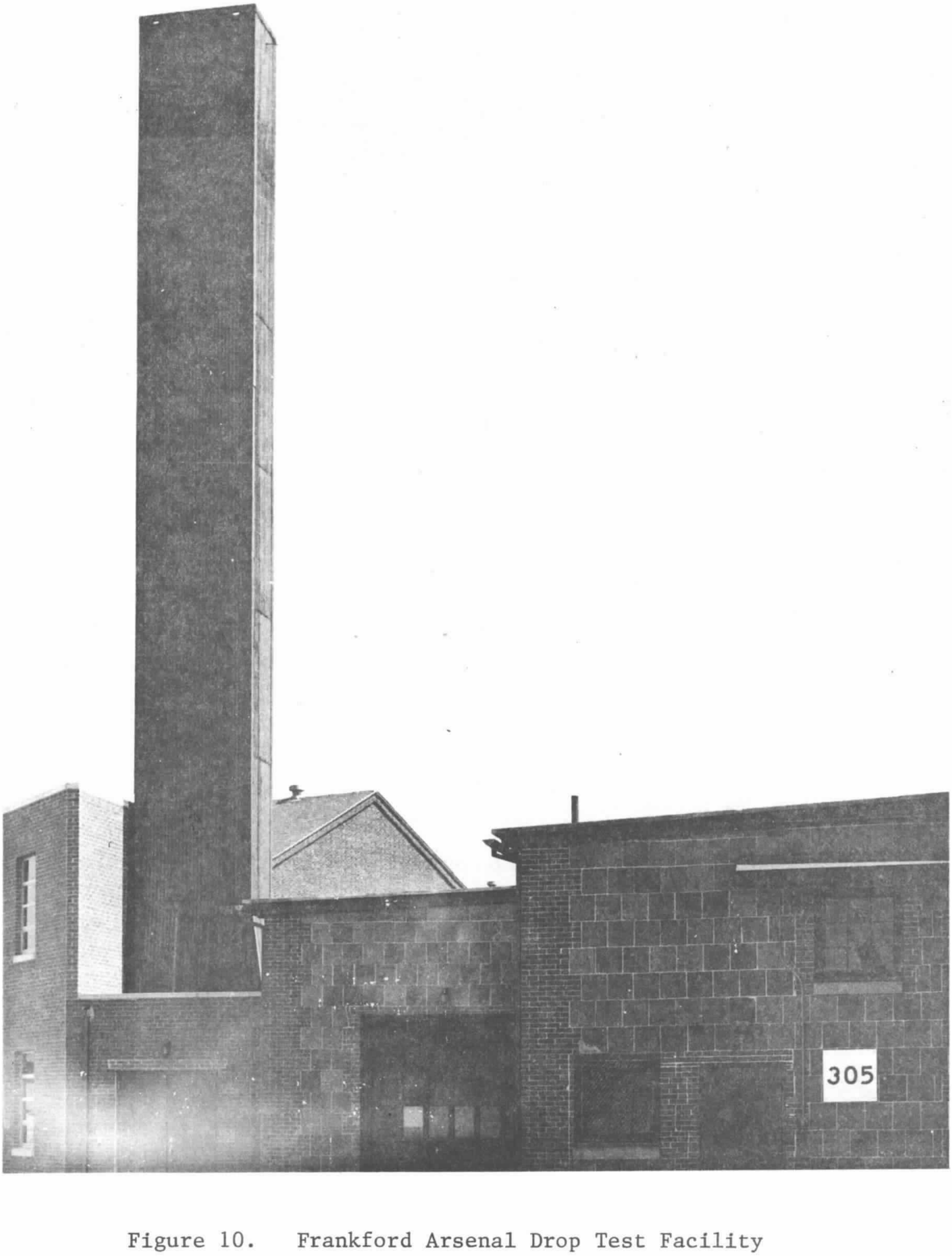


Figure 10. Frankford Arsenal Drop Test Facility

Upon release, the test item falls in an orientation maintained by the guide. At about 14' the item separates from the guide and then free falls the balance of the drop. This technique is used to provide the proper impact angle specified in MIL-STD-331.

Differences between drop test facilities are found in each of the above mentioned areas. Some installations have elaborately constructed towers. It is only in these towers that guides can be used. Other fuze test facilities merely use a crane to hoist the test items to 40 feet. When the projectiles are released, they are subject to gusts which may alter the impact angle. Because of differences in drop tower contruction, the control systems will vary from one installation to another. The basic requirements which result in some uniformity of the test facilities is that impact must be on a steel plate on a concrete foundation.

Procedures for the Drop Tests

The first step in performing the drop test is to assemble the fuze to the inert projectile for which it was designed. The inert projectile should weigh about the same as one that is loaded. A minimum of 10 fuzes are dropped, 2 fuzes in each of five orientations: (1) nose down, (2) base down (3) major axis horizontal, (4) major axis 45^{o} from vertical, nose down, (5) major axis 45^{o} from vertical, base down. The angular tolerance for these orientations is $\pm 10^{o}$. After the drop, the test assembly is inspected to determine if the fuze passed the test. For the Forty Foot Drop test, the fuze must be safe to handle while not necessarily operable. In the Five Foot Drop test the fuze must be both safe to handle and operable, or else safe to handle and not necessarily operable depending on the item's test specification.

Problem Area

In reviewing the Five Foot Drop and Forty Foot Drop tests, it was evident that there was some emphasis being placed on the ability of the drop facility to provide projectile impacts at specific angles. The method which existed for verifying the angle of impact was to maintain a resident inspector at each drop test facility. He watched the projectile falling at a rate of over 600 inches per second (immediately prior to impact), for a 40' drop, and he then used his "expert vision" to verify the angle of impact of the blur he saw. That verification technique was lacking both from the standpoint of safety as well as accuracy. It seemed likely that test personnel involved with loaded fuzes did not want to place themselves in a viewing position where they might be subjected to injury if a test item exploded on impact. There were two solutions considered to solve the verification of impact angle problem. The first alternative was to guide the projectile in a desired orientation through the entire drop, thus insuring proper impact angle. There were several

drawbacks in that technique. The present test method allowed for rebounds, however, the other kind of guide system violated this requirement. In addition, if the projectile was released from the guide immediately prior to impact, there could be losses due to friction which would lessen the shock environment. Finally, even if it was possible to design a system which would overcome those objectionable features, it would probably be very expensive and difficult to standardize into all the drop tower facilities. This first possible solution was therefore eliminated from further consideration.

The second alternative to verify the impact angle was to develop a monitoring technique which would not guarantee a desired orientation necessarily, but would provide visual verification of the actual impact angle. A trial and error technique could then be applied to achieve proper initial orientation to obtain the desired angle of impact.

Test Program

To overcome the problem of verifying the impact angle, the second alternative of developing a monitoring system was chosen. The requirement on the monitoring system was that it provided a visual display of a projectile, at or immediately prior to impact. Two alternatives were considered. First, motion pictures of the impact could be obtained and then played back in slow motion. The other approach would be to use still action photography. Both options appeared to contain problem areas. Using motion pictures, immediate results could not be achieved. First, the film would require development and then a projector, capable of slow motion, would have to be used. This obstacle eliminated further consideration of motion pictures. Immediate (15 sec) results could be obtained using still action photography with the Polaroid cameras which are available today. However, there was some difficulty in attempting to "catch" (photograph) the projectile immediately prior to impact. This necessitated auxiliary equipment, whose purpose was to trigger a camera at a certain instant in time. This involved detection of a moving object and then "freezing" its motion to allow for a non-blurred photograph. To detect the falling projectile, two operations were considered: radar and ballistic screen. Initial testing proved radar unreliable and the ballistic screen a good alternative. There was obviously some delay between detection and photographic triggering which had to be considered. A literature review discovered a unit which appeared to meet the monitoring system's requirements for a variable time delay. Initial testing confirmed the unit's acceptability. To "freeze" the falling projectile, electronic flashes were procured. The next problem considered, was how to analyze the information obtained on a photograph. It was recognized that if the projectile's major axis was not parallel to the plane of the photograph the angle measured on the photograph would not be the true angle with respect to the impact surface. This was a problem of descriptive geometry. In order to obtain the true impact angle, two orthogonal photographs were

required. By wiring together the electronic circuitry of solenoid-actuated triggering systems, simultaneous orthogonal photographs could be obtained by using two Polaroid cameras. Measurements of the angles from those two photographs would then provide the true impact angle, if an appropriate analysis scheme could be developed. Accordingly, Dr. Milton Schwartz, and others of the Pitman-Dunn Laboratories were asked to derive an analysis method that would provide an immediate answer of the impact angle and still be in a form such that relatively unskilled personnel at each test facility could use it. This analysis scheme was developed and is included in Appendix F.

Instrumentation

The system which was designed (see Figure 11) consisted of a sensing unit in the form of a ballistic screen, a four channel program-pulse-interval generator for variable time delay, two solenoid operated Polaroid cameras and two electronic flashes. The solenoids were operated by means of a remote control box. The system assembly and details are shown in Figures 12, 13, 14, and 15. A schematic of the control box is shown in Figure 16.

The ballistic screen was located at some distance above the impact surface. The cameras and electronic flashes were located near the impact surface at right angles to each other. For example, camera #1 and flash #1 faced the same direction, camera #2 and flash #2 at a ninety degree angle.

After release from the 5' or 40' height, the free-falling test item passed through the ballistic screen. The ballistic screen was basically a receiver and transmitter network which established a constant beam of light over a cross sectional area in the drop tower, and as the projectile fell through it, it momentarily broke this light beam which caused the ballistic screen system to emit a pulse. This pulse was fed into the interval generator. The receipt of this detection signal initiated the delay circuitry. This delay was programmed from 10 microseconds to 10 seconds. Fundamental physics was used to estimate the amount of delay required to obtain photographs of the falling projectile immediately prior to impact (see Appendix G). At the end of the delay period, the interval generator provides a voltage shift from 0 volts to 12 volts dc. This signal was fed into the control box which operated the solenoids mounted on the cameras. The solenoids actuated the shutters, one solenoid on each camera, which in turn triggered the electronic flashes. They provided stop action lighting for the two right angle photographs. The following lists the components of the Drop Tower Monitoring System:

1 Ballistic Screen: Electronic Counters, Inc., Model No. M6100-PT

1 Pulse Interval Generator: Electronic Counters, Inc., Model No. 5651-M

2 Electronic Flashes: Metz Mecablitz, Model No. 213.

2 Cameras: Polariod, Model No. 440, Solenoid actuated

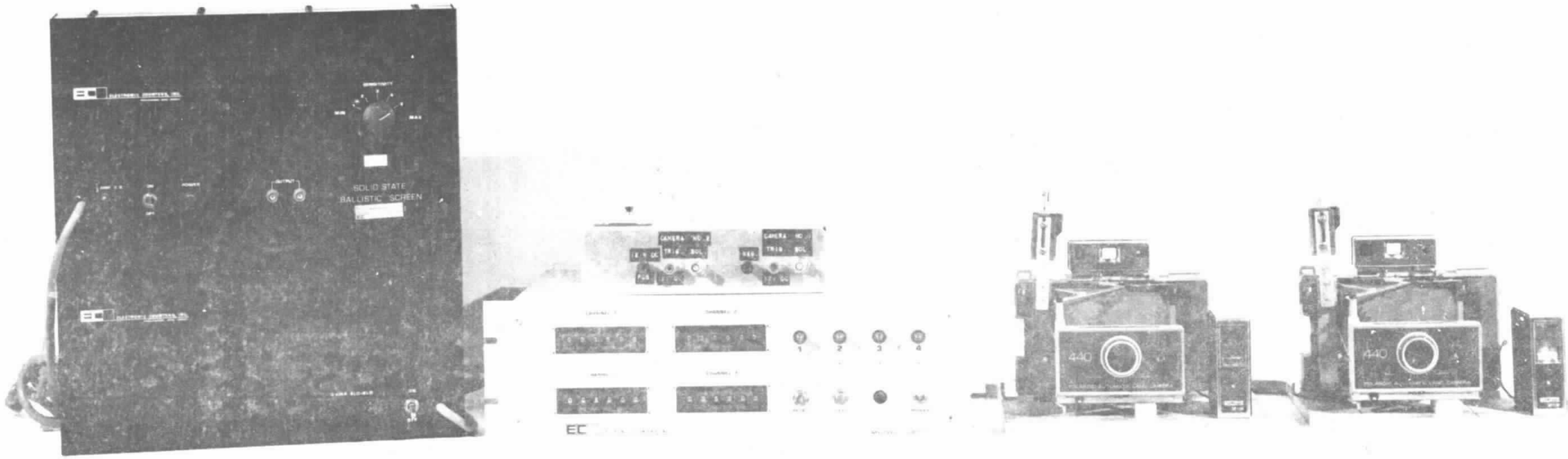
1 Control Box

Installation of the Drop Tower Monitoring System

Modification of the existing Drop Tower Facility at Frankford Arsenal was required to install the monitoring system. The work was centered in and around the area of the impact surface. First the plywood sheathing was stripped. Then after the steel walls were laid out, holes were cut for the installation of the ballistic screen and cameras. Next, two 1/8" steel boxes for the cameras were hung. The support flanges for these boxes were welded through two of the holes, -one at the base of the back wall and one at the base of the right side wall. These boxes were centered 10 inches off the floor. A 1/8" steel box for containment of the receiver portion of the ballistic screen was then welded on the right side wall and centered 44 inches above the floor. Mounting the box, for the ballistic screen transmitter to the left side wall, required special attention. The outside brick wall of Building 311 was too close to the inside steel wall at the base of the drop tower, and the result was that there was not enough clearance to pass a steel box through the cut hole in the left side wall. Therefore, a steel box was welded together, and the box was then welded to the surface of the left side wall. This box was also mounted 44 inches above the floor; the same height as the receiver box. This resulted in the plane of the light beam being parallel to the floor. Protective covers for both cameras, transmitter, and receiver boxes were then designed and fabricated. The covers for the camera boxes had holes cut; one for the camera lens and one for the electronic flash. These covers were made to slide open and shut for easy access. The covers for the transmitter and receiver boxes had long narrow slots which were cut to allow for a directed light path. Finally, appropriate holes were cut in the plywood sheathing which was then reinstalled. The remainder of the angle of impact verification system, including the interval generator and control box, was placed on a table in the control room, and the system was then interconnected according to Figure 12.

Operation of the Monitoring System

Initially, measurements were made on a static object (a ruler held in a vise) in fixed orientations from the horizontal plane. This was done to determine the validity of the analysis scheme. Sets of photographs were taken by physically triggering the solenoid actuated cameras (the ballistic screen and interval delay unit were not needed in this experiment). Variations of the fixed positionings were made to account for the different possible octant orientations, as well as the small and large acute angle possibilities. Excellent



Ballistic Screen

Control Box

Time Delay Unit

Solenoid
Camera
Flash

Solenoid
Camera
Flash

Figure 11. Drop Tower Monitoring System Components

agreement was found in comparing the theoretical analysis to the measured result from two othogonal photographs. In all instances, the difference was less than 2 or 3 degrees, which could easily be attributed to the accuracy of measurement by using a protractor. Hence, the analysis scheme was verified. The next task was to confirm that the ballistic screen and delay unit could be used to "catch" a moving object. This was done by subjecting an inert projectile to a MIL-STD-331 Five Foot Drop test while operating the monitoring system inside the drop tower. Initially, the pulse interval generator was adjusted for a 220 ms time delay corresponding to a theoretical calculation for a Five Foot Drop test (see Appendix G). Photographs were then made of the falling projectile for all five required orientations. These pictures are shown in Appendix H as H-1, H-2, H-3, H-4 and H-5. As can be seen, only slight variation of the time delay was required to catch the moving object at the desired height above impact (intersecting the horizontal reference line). The important aspect was that the system did catch the falling projectile, and the theoretical time delay corresponded well with the required delay. In essence, it was demonstrated that the monitoring system and analysis scheme behaved well under a field test condition.

Recommendation

It is recommended that a monitoring system consisting of: a ballistic screen, pulse generator, two solenoid actuated cameras and electronic flashes, a control box , and Dr. Schwartz's and other's analysis scheme, be adopted as a required technique for confirming impact angles in the drop tower. The system accuracy is at worst ±5 degrees as compared to the MIL standard requirement of ±10 degrees. At the present time the system, as stated, can be purchased for approximately $4000.

Implementation

A recommendation for including the monitoring system into MIL-STD-331 will be presented to the Fuze Engineering Standardization (FES) Work Group. In the interim, plans are already underway for including the system as part of future Industrial Equipments Lists (IEL). The Drop Tower Monitoring System can be referenced by Frankford Arsenal Drawing Nos. 8649074 thru 8649077, inclusive. These drawings are included in Figures 12, 13, 14 and 15.

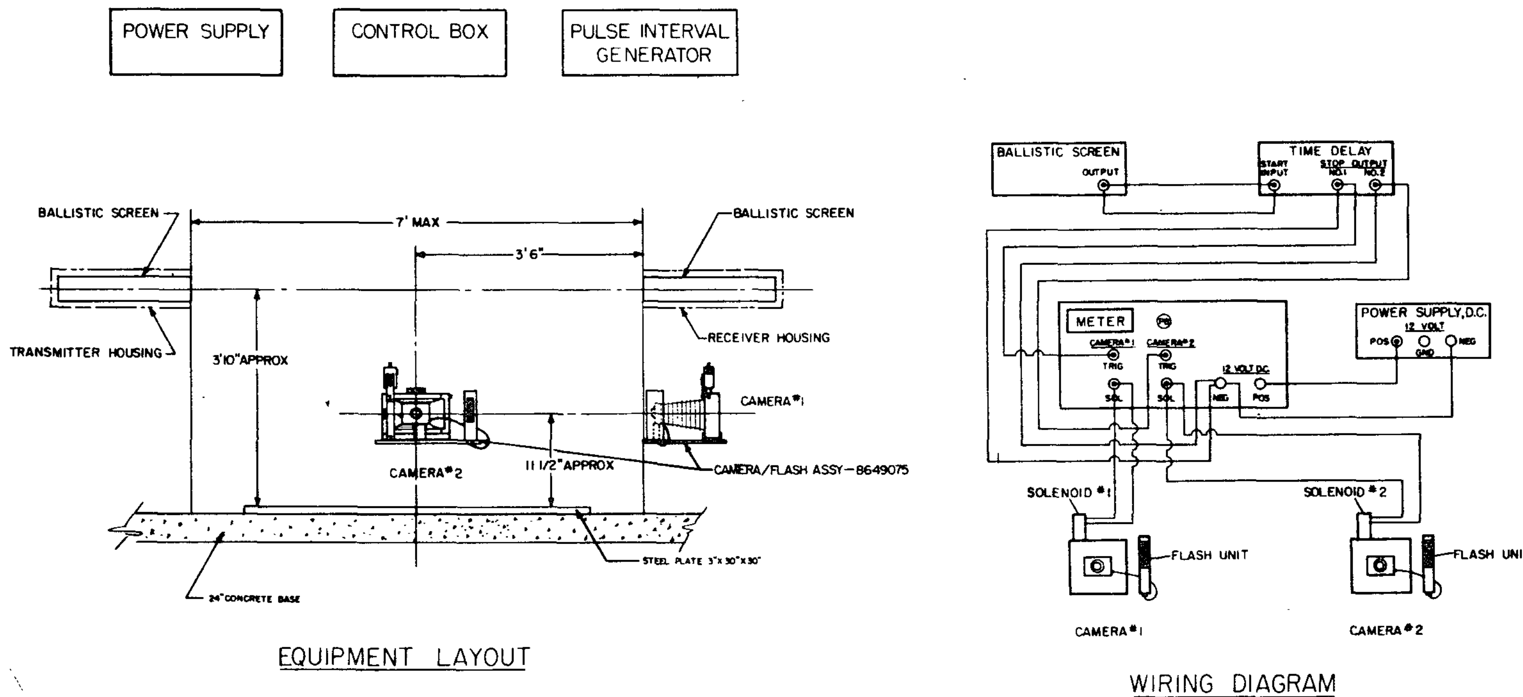


Figure 12. 40 Foot Drop Tower Monitoring System - Frankford Arsenal Drawing No. 8649074

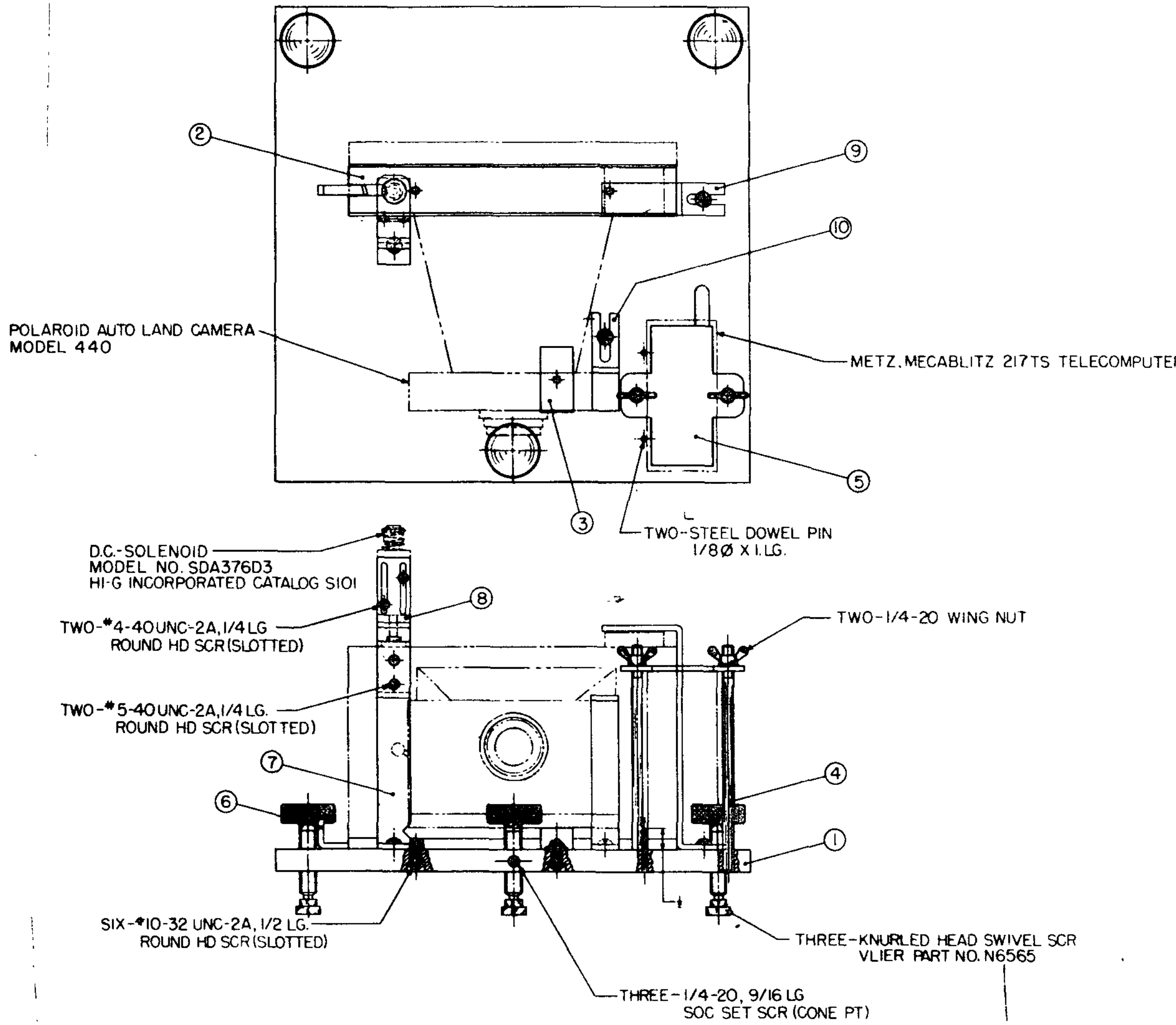


Figure 13. Camera/Flash Assembly-Frankford Arsenal Drawing No. 8649075

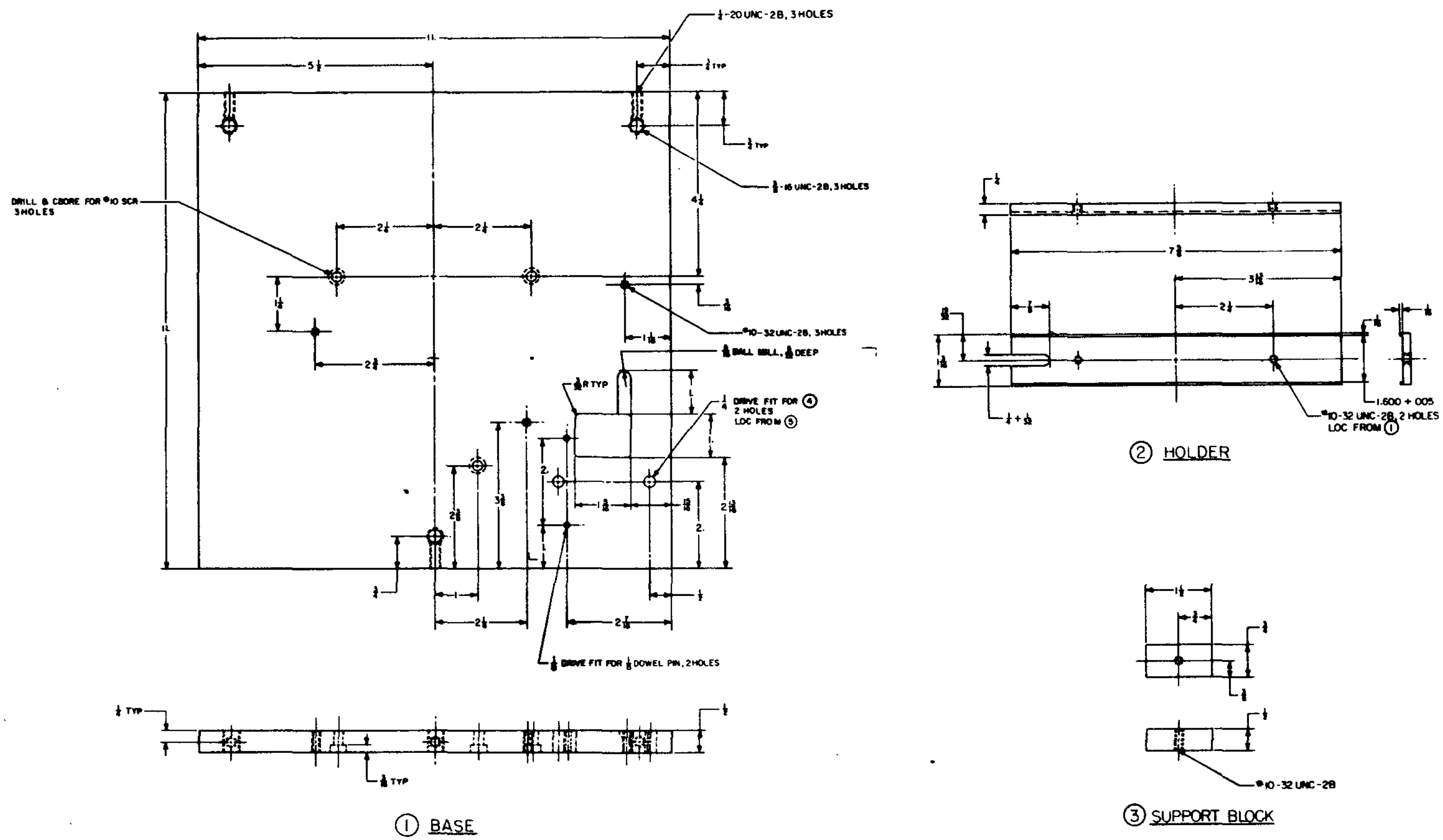


Figure 14. Details of Camera/Flash Assembly-Frankford Arsenal Drawing No. 8649076

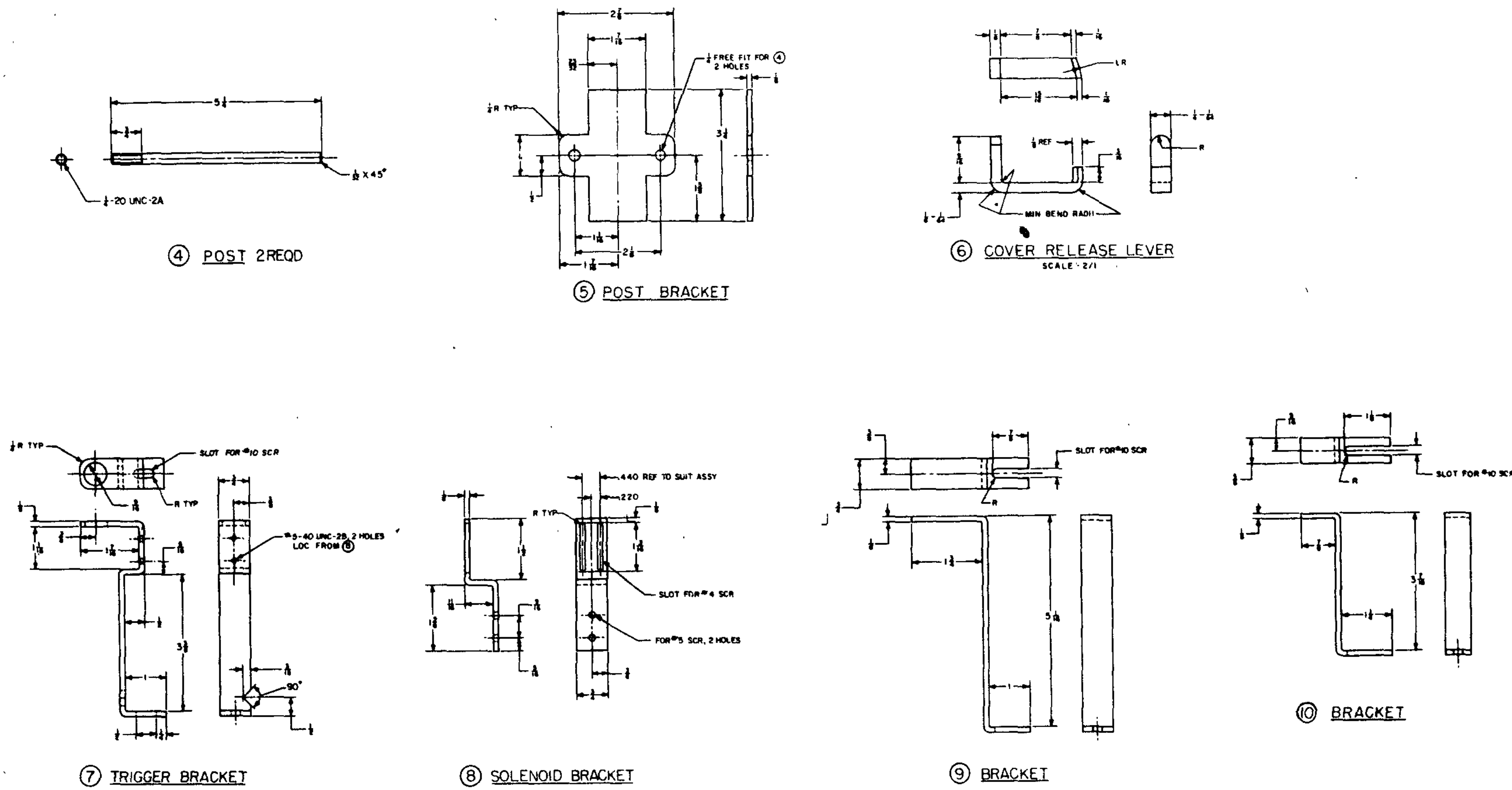
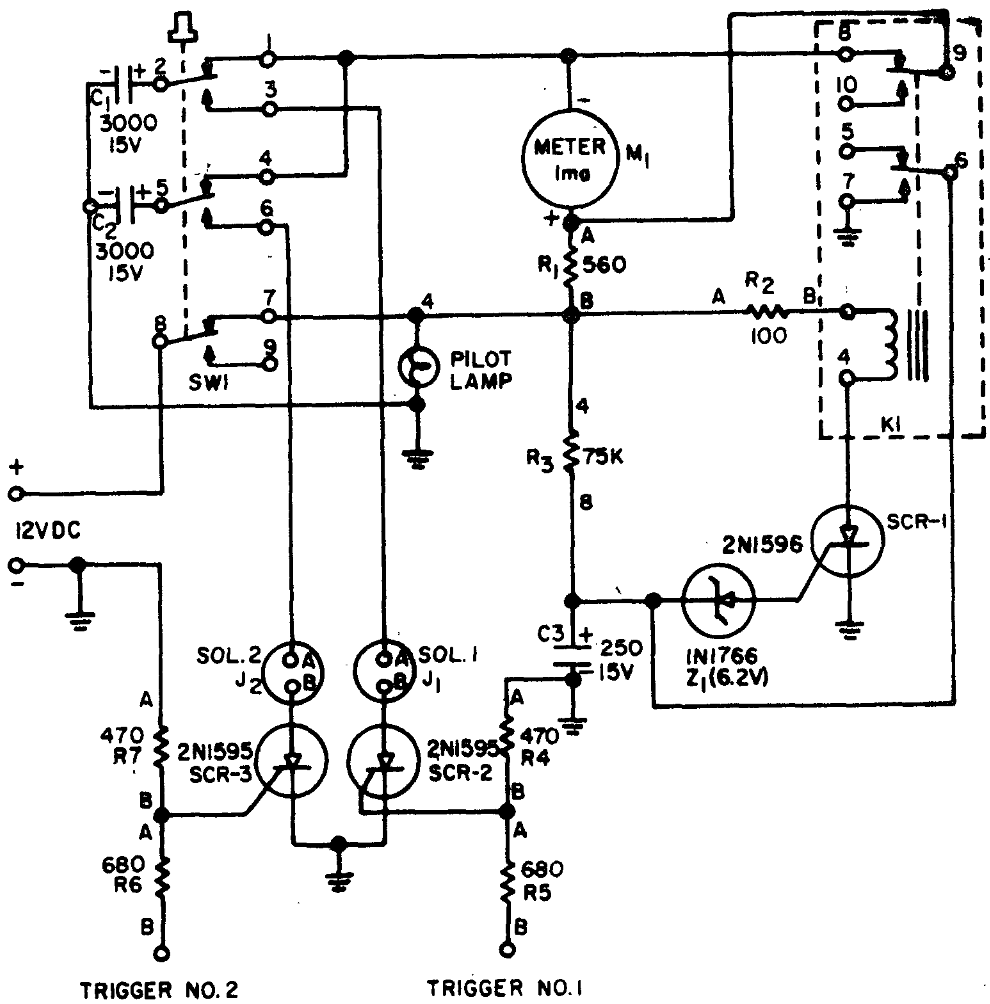


Figure 15. Details of Camera/Flash Assembly-Frankford Arsenal Drawing No. 8649077



1. All resistors are in ohms and have a tolerance of ±10% except R_3 is ±5%

2. All capacitors are in microforads and have a tolerance of -10% + 150%

Figure 16. Schematic of the Control Box and Solenoids-
Drop Tower Monitoring System

JOLT MACHINE MONITORING SYSTEM

Introduction and Background

The purpose of this subproject was to develop a method for monitoring the Jolt test in MIL-STD-331. The overall objective was to produce more uniform testing throughout DOD and contractor fuze test facilities by providing a calibration technique capable of insuring conformance to a defined Jolt environment.

In order to understand the difficulty in developing a monitoring system for the Jolt test, some background on shock test specification is helpful. There are at least three ways of specifying a shock input to a laboratory test item. First, a time history consisting of a peak g-level, pulse width in units of time, and pulse shape, can be used to describe the shock environment. For example, MIL-STD-810B specified a 100 g, 6 ms., half-sine shock pulse as a high intensity test for ground equipment. Another method used in specifying a dynamic input which has found recent acceptance is shock (response) spectrum. This is usually employed when the field time history is complex and cannot easily be reproduced in the test facility. The technique is to compute shock spectra of accelerometer measurements which were taken in the field, and compare them to spectra of simple pulses obtainable on laboratory shock test equipment. Since it can be shown mathematically that different time histories can yield the same shock spectra, the object is to find a laboratory shock spectrum which best fits the field data. Sometimes the spectra match up very closely; however, the majority of the comparisons require sound engineering judgement to assess what degree of overtest or undertest is tolerable. A third technique is to specify a test machine. This is used to produce more of a real life test environment than can be obtained by standard laboratory methods. The major drawback of specifying a test machine is that the shock input may be complex, and it can be difficult to assess the machine's performance. The Jolt machine as specified in MIL-STD-331 exemplifies this difficulty. There are several components, some of which are subject to wear that influence the shock environment. The result is variation which makes standardization of the test very difficult. The basis for a monitoring system is to act as a performance evaluator so that more uniformity will exist. For a time history, the performance indicators of peak g-level and pulse width are clearly defined. Using shock spectrum, the acceleration-frequency curve can relate performance. For a test machine, these indicators are not defined at all. The foremost difficulty in attempting to develop a monitoring system for the Jolt machine was to determine what criterion would be used to evaluate the machine's performance, and then to design a system which would sufficiently describe that performance.

Two monitoring systems were designed. The first was based on the time history as a performance evaluator; the second was developed on the basis of

the shock spectrum. The systems were subjected to test and evaluation to determine their acceptability for possible inclusion into MIL-STD-331.

Requirements of the Monitoring System

In addition to being sufficient to describe the Jolt machine's performance, several other requirements were placed on the design of the monitoring system:

1. The system had to provide an immediate "yes" or "no" answer to whether the Jolt machine met the requirements of MIL-STD-331. It was undesireable to design a system which required a significant delay period for analysis.

2. There must be a minimum test time. This implied a minimum amount of external test and calibration equipment. Internal calibration built into a single analysis unit was felt desireable.

3. The system must be easy to use so that reasonably unskilled test personnel could operate it. No complex wiring interconnections were tolerable.

4. The operating procedure should minimize the chance for operator error. For example, there should be no calculations required which might result in mathematical mistakes. Also, the calibration and operating procedures should contain simple steps to follow.

5. Finally, the system had to be economically practical. If units were to be purchased for several test facilities, the price per unit had to be minimized. Therefore, system cost was limited to a few thousand dollars.

Instrumentation

Several different monitoring systems were investigated. These systems fell into one of two categories, based on time history or based on shock spectrum. They are as follows:

TIME HISTORY

1.	Accelerometer,	adapter,	shock amplifier,	digital display
2.	"	"	"	oscilloscope
3.	"	"	"	oscillograph

SHOCK SPECTRUM

1. Accelerometer, adapter, shock amplifier, electronic shock spectrum analyzer, x-y plotter.

2. Accelerometer, mechanical shock spectrum analyzer, shock amplifier, digital display.

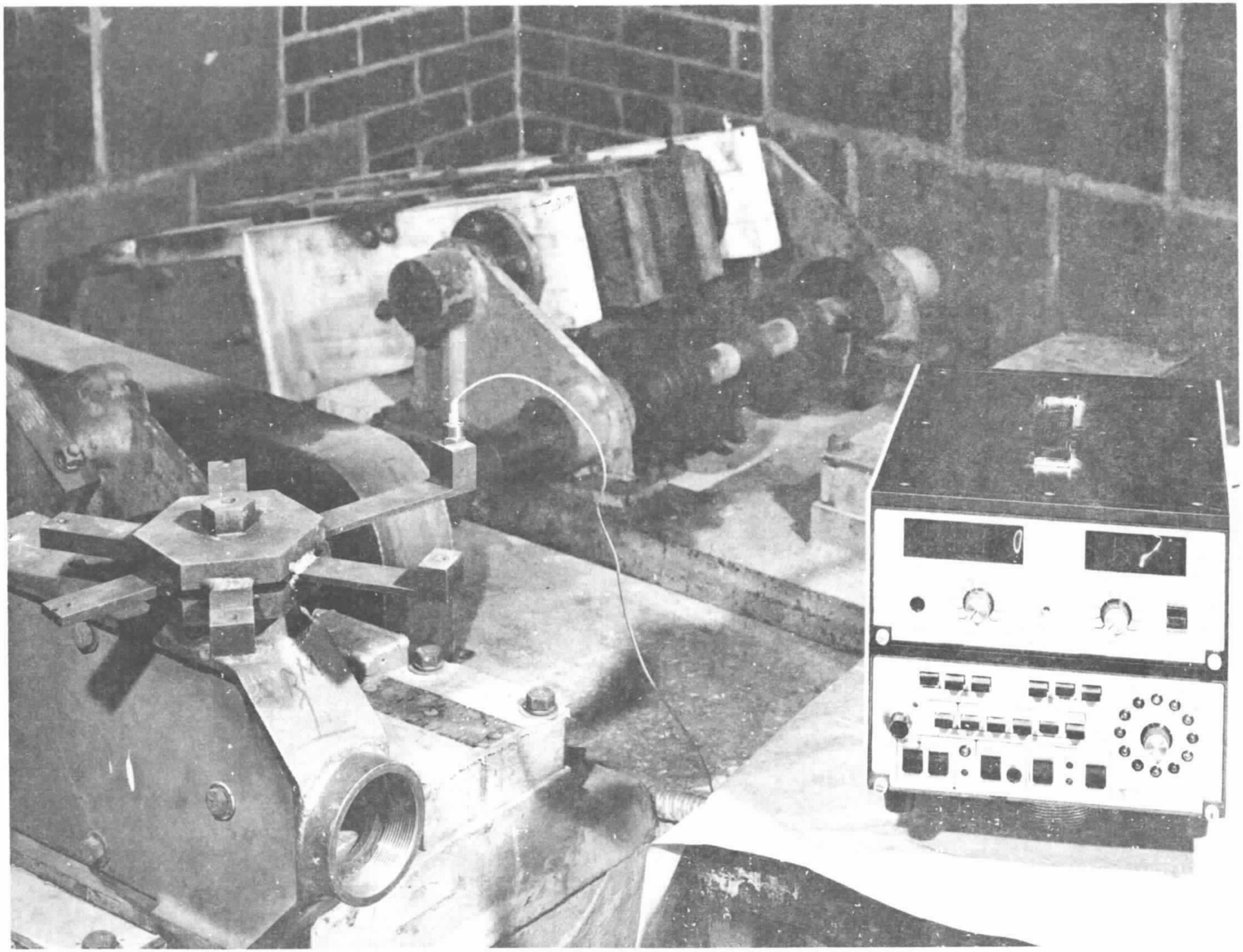
While reviewing the time history systems it became apparent that the shock amplifier with digital display met the design requirements the best. This technique gave instant results and provided the best resolution. The peak g-level and pulse width were clearly indicated digitally, immediately after the shock pulse. No further measurement or data manipulation was required to assess the performance factors. An Endevco Model No. 2740A shock amplifier and 2742AM5 display piggy-backed in a portable carrying case were then purchased to serve as the prototype time history system.

A literature survey was made to assess commercial shock spectrum analyzers. However, after considering the cost and the added requirements of simplicity of use and operation, it was decided to eliminate these complex electronic analyzers. Instead, an attempt was made to design and fabricate in-house, a structure which would serve the function of a shock spectrum analyzer and better meet the design requirements. This system and its design are described in detail in Appendix I. Fundamentally, the structure consists of six cantilever beams, each designed to a predetermined natural frequency. An accelerometer mounted at the free end measures each beam's response to the shock input at the fixed end. By its definition, a shock spectrum is a plot of peak acceleration responses of one degree of freedom systems. For the relatively simple pulse of the Jolt shock, this frequency-response plot can be approximated by knowing a few points on the curve. Therefore, by measuring the peak responses of each of the beams, six points of the spectrum are identified. If the natural frequencies of the beams are judiciously chosen, this technique is sufficient to evaluate the Jolt machine's performance. Using this structure, in conjunction with the Endevco shock amplifier and display, provides the required input of peak g-level response. (see Figure 17). A drawing of the mechanical shock spectrum analyzer is shown in Figure 18.

Test and Evaluation of the Systems

Time History System

An adapter was designed and fabricated for use with the time history system. This fixture, placed on the Jolt arm, was made to accept an accelerometer in the "nose-up" position. The Jolt machine was then operated and measurements were made on arms #1 thru #4. The results indicated that the g-levels were



Note: Six beam fixture is shown mounted in the "nose-up" position and interconnected to Endevco Shock Amplifier and Display Unit.

Figure 17. Jolt Machine Monitoring System -- Shock Spectrum Technique

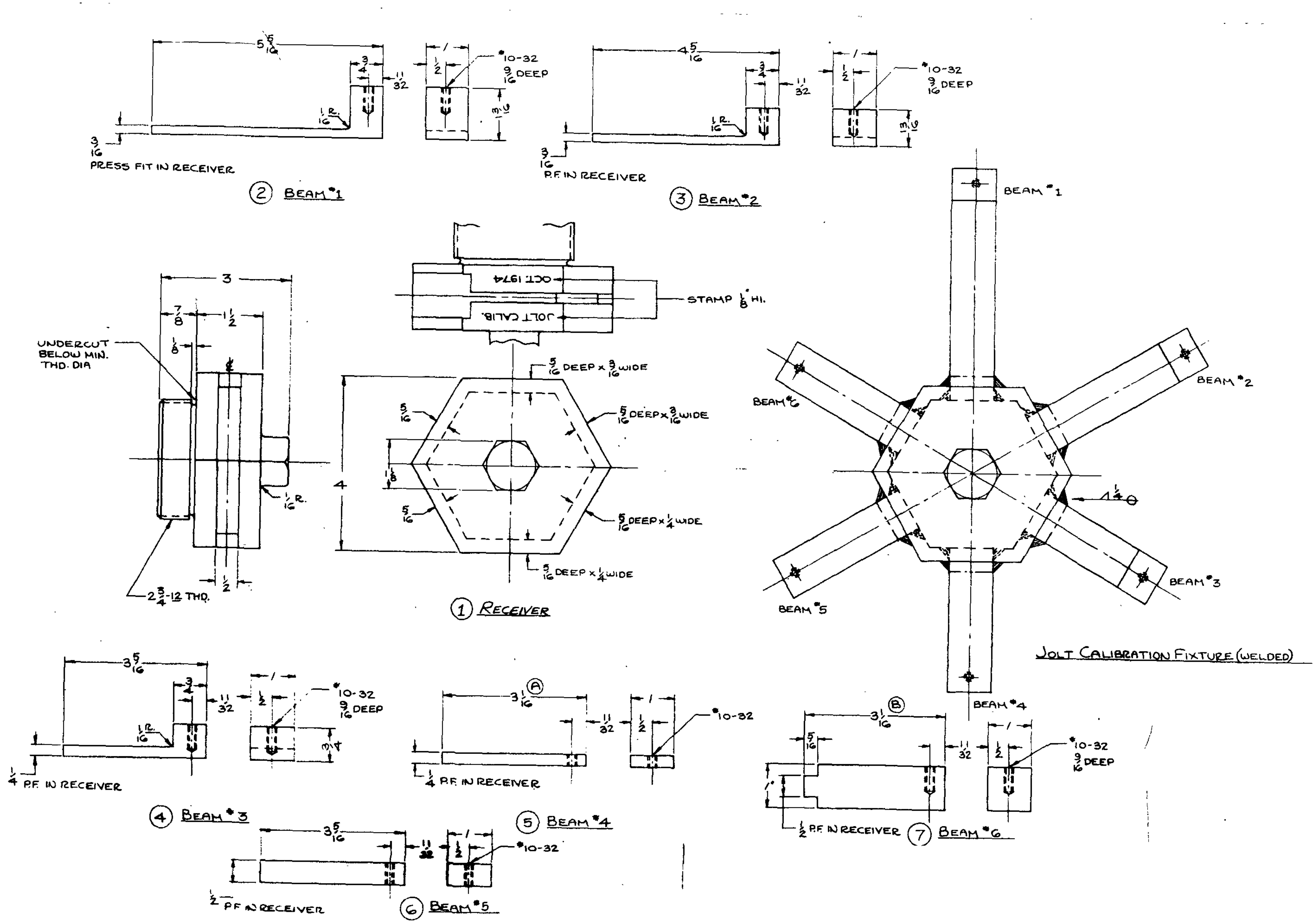


Figure 18. Mechanical Shock Spectrum Analyzer for Use in Calibrating the Jolt Machine. Frankford Arsenal Drawing No. SV-741008

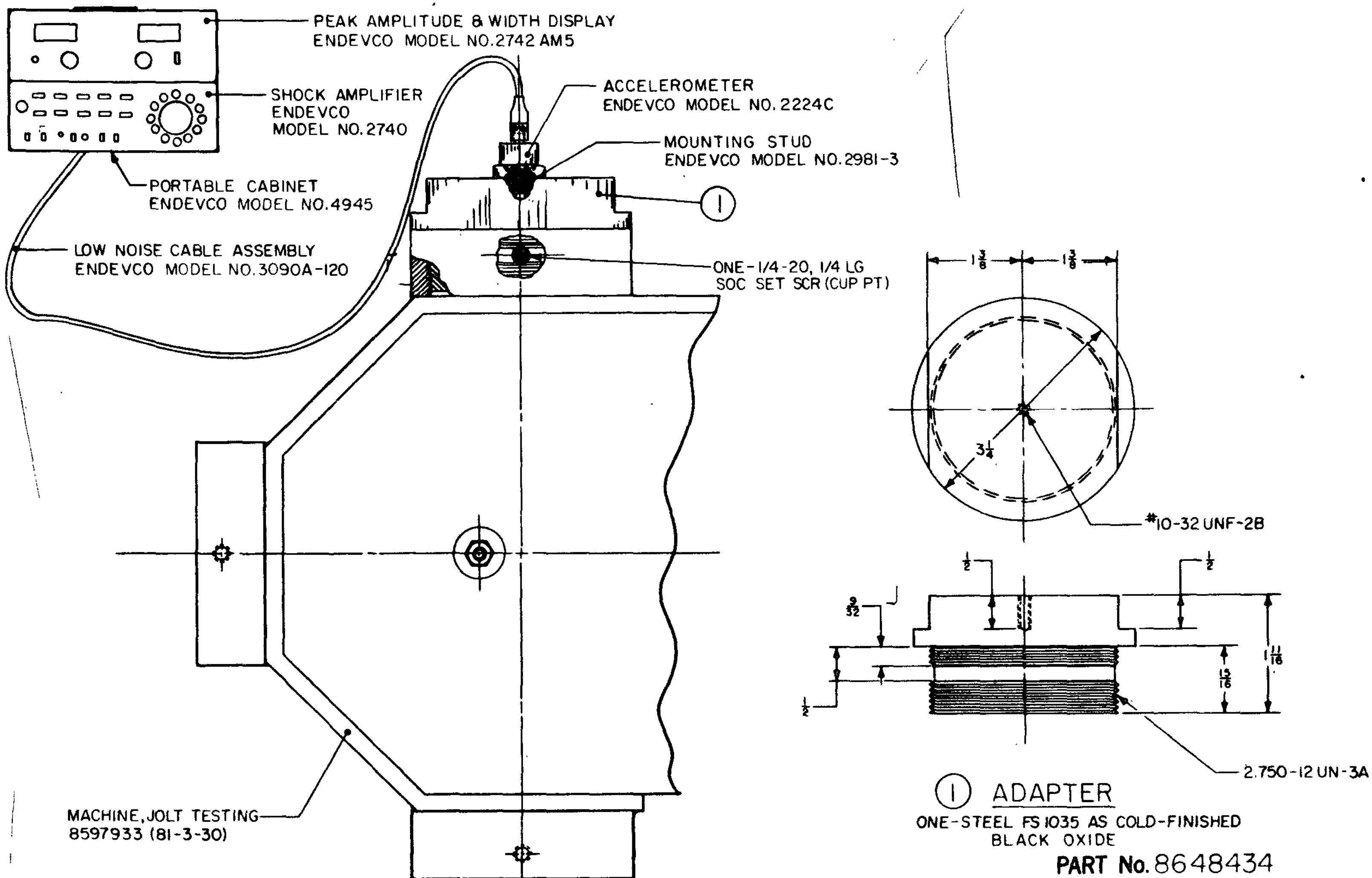


Figure 19. Jolt Machine Monitoring System-Time History Technique

250 ± 25g's and the pulse widths were 1.8 ± 0.3 ms. This agreed with previous oscillographs made in the Jolt test subproject of this report for an arm with a 3 lb. test load. It should be noted that the entire procedure, including system calibration and measurements on all 4 Jolt arms, was completed within 15 minutes. Figure 19 is a drawing of the time history system including all components and interconnections.

Shock Spectrum System

The shock spectrum system was then tested. The specially designed structure to approximate the shock spectrum was placed in the "nose-up" position on the Jolt arm. Measurements were made on all six beams of the structure and the results were compared to the previously measured shock spectra of an arm with a 9 lb. test load. Note: (This structure weighed about 10 lbs. vs. the 3 lb. adapter.) The correlation of results was good; however, a few drawbacks were detected. First, since six measurements were required for each Jolt arm, the accelerometer had to be physically moved from beam to beam on the measuring structure six times. This was time consuming and also required extra effort by the operator. This was contrary to the goal of simplification. In addition, it was in this effort that the existence of angular acceleration in the Jolt arm became apparent. This phenomena was detected when radically different g-levels were obtained on two different arms. The unit was highly dependent on how the structure threaded into the "nose-up" socket. For example, with the structure tightened in the Jolt arm, if the lowest frequency beam was directed in toward the pivot shaft, a peak g-level of about 170 was measured. On a different Jolt arm, when the structure was secured in the machine, the lowest frequency beam was directed outward, away from the shaft. This time, the measured response peaked at about 360 g's. The only plausible explanation was that the low frequency beam was seeing a different input, and the only way this could occur was if the input was a function of the radical distance from the impact surface. It was therefore decided that the shock spectrum monitoring system could be an acceptable alternative only if the structure were shimmed to provide a given orientation to the cantilever beams when secured in the Jolt machine.

Comparison of the Tested Systems

The following summarizes how the two systems compared with regard to the design requirements:

Requirement 1. Provide immediate answers: Since both systems used the same shock amplifier and display unit, both systems provided immediate answers. However, the time history system required one measurement per arm whereas the shock spectrum method required six. For measurements of all 4 Jolt arms, time history resulted in 4 readings while shock spectrum required 24.

Requirement 2. Minimum test time: In using the time history technique the adapter fixture was moved from one arm to another with no accelerometer manipulation. The shock spectrum technique required the same move of the structure from one arm to another, but in addition, on a given Jolt arm, the accelerometer was removed and placed into each of the six available locations on the structure. The Jolt machine had to be shut down and restarted each time the accelerometer was moved resulting in a significantly longer test time. (approximately 15 minutes for time history; 45 minutes for shock spectrum).

Requirement 3. System must be easy to use: The choice of the shock amplifier and display unit resulted in equal facility of use with both systems. Relatively unskilled personnel should have no difficulty using either the time history of shock spectrum method.

Requirement 4. Simple operating procedures: As previously mentioned, the shock spectrum system involved more hardware manipulation. However, the operating procedures for both techniques involved nothing more than pushing a few knobs and removing and replacing fixtures with a wrench.

Requirement 5. Economically practical: The shock spectrum system's cost was more because of the added complexity of the special structure vs. the more simple accelerometer adapter. The number of manhours for fabrication was 40 for the special structure vs. 16 for the adapter. There was an additional insignificant cost difference to account for the longer test time in using the shock spectrum system.

Requirement 6. Sufficient to describe the Jolt machine performance: In the Jolt test subproject of this report, the question of how to evaluate the shock environment was investigated. It was stated that the Jolt time history consisted of a main pulse with higher frequencies superimposed. In reviewing the shock spectra and time histories from the Jolt data it was apparent that the pulse shape approximated a half-sign. While there was merit in saying that the shock spectrum more clearly described the Jolt environment, there was also merit in saying that a time history described the shock sufficiently. The degree to which a time history described the test was purely subjective and the design of a new Jolt test using a simple pulse with performance indicators of peak g-level and pulse-width was already being considered by the FES. Therefore, it was felt that the time history system was sufficient to calibrate the Jolt machine.

Recommendation

1. It is recommended that the time history system be accepted as a standard calibration technique for the Jolt machine. This system is easy to use and operate, provides immediate answers, requires a minimum test time, is

sufficient to evaluate the Jolt machine performance, and is economically practical. It is estimated that an entire system consisting of an accelerometer, a shock amplifier and display unit with carrying case and adapter fixture can be purchased for about $3500.

2. When this system is used with the 3.5 lb. adapter fixture in the "nose-up" position on the Jolt arm the following figure should be used as standards for peak g-level and pulse-width.

Peak acceleration: 250 $\pm$ 25 g's

Pulse width: 1.8 $\pm$ 0.3 ms.

Any significant change in weight of the adapter fixture will result in changes to the above standard levels.

Implementation

A recommendation for including the time history system as a standard calibration technique in the Jolt test of MIL-STD-331 will be presented to the Fuze Engineering Standardization (FES) Working Group. In the meanwhile, plans are underway to include the system as a required calibration technique in future Industrial Equipment Lists. The system can be referenced by Frankford Arsenal Drawing No. 8648434 (Figure 19).

PROJECT SUMMARY

The purpose of this three year project was to improve the testing of fuzes by incorporating modern technology into test methods. This involved establishing new tests (when required) and developing new techniques, for unifying those tests throughout the Department of Defense and Industry, in order to insure accuracy, repeatability and reliability. This project placed emphasis on improving currently used but inadquate tests for fuzes. Those efforts were concentrated in four main areas. They were:

a. Developing new MIL-STD-331 tests.
b. Revising existing MIL-STD-331 tests.
c. Modifying existing test equipment.
d. Developing systems to verify that test equipment was operating properly.

Table 11 lists the MIL-STD-331 tests which were considered under this three year project. The deficiencies, proposed solutions and results of this program are listed.

The following is a brief summary of the project history from inception to completion.

A. Fy 70 - Initial funding of $35,000 was received June 1970.

(1) Concepts were developed for improving the nine MIL-STD-331 tests shown in Table 11.

(2) Three new test methods were prepared for DOD coordination. These included Salt Fog test #107, Dust test #116, and Waterproofness test #108.

(3) Instrumentation for monitoring the Jolt test and Drop tests were acquired. A g-meter and accelerometer was purchased for monitoring the Jolt machine. Purchases of a radar device similar to a burglar alarm system, two Polaroid careras, two electronic strobe lights and two solenoids to operate the cameras were made for developing a system to verify impact angles in the drop tower.

(4) Three new test procedures were published. These included the three tests listed in item (2). This publication was significant because it enabled full implementation of this program's efforts in a very short time after its completion.

B. FY 73 - Interim funding of $95,000 was received October 1972.

(1) Two new test methods were prepared for DOD coordination. The two tests were Transportation Vibration #104 and the Five Foot Drop test #111.

(2) Materials were purchased for modifying two test machines (1 Jolt and 1 Jumble). Snythetic materials (nylon, polyurethane, teflon and polyethylene) were obtained for possible replacement of the natural materials (oak, wood, maple wood and leather) used on the Jumble machine (jumble box liner) and the Jolt machine (arm, pad and anvil).

(3) A Breadboard test, set-up to measure drop angle impacts, was developed and built. A prototype system was assembled to photograph the orientation of a falling fuze immediately prior to impact. The system incorporated two solenoid operated Polaroid cameras at right angles to each other, a radar device which triggered the cameras upon sensing the falling fuze, and a strobolum triggered by one camera to illuminate the fuze with two high intensity flashes.

(4) Two new test procedures were published. The two tests listed in item (1) were accepted by the FES Working Group and published in MIL-STD-331.

(5) A second generation instrumentation system for monitoring the Jolt machine was purchased. Initial testing had indicated that the original g-meter was insufficient to provide the desired information (the meter had averaged the primary shock with all the following shock waves). Therefore, a peak reading g-meter was purchased.

(6) Contracts were initiated for purchasing a second generation drop tower monitoring system. The initial prototype was found to have unacceptable, variable, strobe delays due to inherent electromechanical variables in the two camera systems. A new system was proposed using ballistic screens to trigger a multi-channel programmed delay unit. Procurement of the ballistic screens and delay unit was initiated.

C. <u>FY 74 - Final funding of $120,000 was received October 1973.</u>

(1) Three revised test methods were prepared for DOD coordination. These included Fungus resistance test #110, Jolt test #101 and Jumble test #102.

(2) The Jumble machine was modified and evaluation tests were made. A pendulum test was developed in-house, and performance tests indicated that polyurethane and polyethylene produced similar shock environments as maple wood when subjected to simulated test conditions found in the Jumble box. Wear testing indicated the synthetics lasted much longer than the maple. (see Jumble test subproject in this report)

(3) The Jolt machine was modified and evaluation tests were made. Results indicated that material substitution could be made without significant change to a standard Jolt test environment. In addition, an investigation of the shock parameters indicated that it was not necessary to have all four arms operating when performing a test. (see Jolt test subproject in this report)

(4) The Jolt machine monitoring instrumentation was received and evaluation tests were made. A second system, based on shock spectra was designed and fabricated. This was compared to the time history system (peak reading g-meter and pulse-width display). The time history technique proved to be superior for use as a standard calibration system for the Jolt machine (see Jolt Machine Monitoring System subproject in this report).

(5) The contract for the Drop test instrumentation was awarded, delivery was made, and the system was evaluated. The existing drop tower in Building 305 was modified for system installation. The drop tower monitoring system was evaluated by subjecting a projectile to a Five Foot Drop test and photographing the impact angles. An analysis scheme was developed by the Pitman-Dunn laboratories for use with the instrumentation to provide immediate answers (see Five Foot and Forty Foot Drop Test Monitoring System subproject in this report).

(6) Three new test methods were published. The three tests listed in item (1) were accepted by the FES committee and published in MIL-STD-331 and MIL-STD-331A.

In summary, eight test methods in MIL-STD-331 were revised as a result of the efforts in this project. In addition, two monitoring systems have been developed which may result in future revisions.

Table 11. MM&T #5706310, 5736310 and 5746310 Project History

MIL-STD-331 Test Method	Deficiency	Proposed Solution	Result
Salt Fog	salt concentration too high	use more realistic concentration	Revision to MIL-STD-331
Dust	test outmoded	update test method	" "
Waterproofness	inadequate for hermetically sealed fuzes	utilize more sensitive tests	" "
Five Foot Drop	too severe	lessen requirements	" "
Transportation Vibration	too mild	increase test levels	" "
Fungus	test outmoded	update test method	" "
Jolt	machine outmoded; results questionable	modify machine; develop calibration system	Revision to MIL-STD-331; jolt machine monitoring sys.
Jumble	machine outmoded	modify machine	Revision to MIL-STD-331
Five Foot and Forty Foot Drop	impact orientation unknown	develop monitoring system	Drop tower monitoring sys.

APPENDIX A

Endurance Test of Jolt Machine Substitute Materials

After finding that it was possible to substitute materials for the wood arm and leather pad which maintained approximately the same dynamic environment, the decision was made to determine if there were any detrimental effects to nylon and polyurethane from long term exposure to Jolt test conditions. Therefore a comparison test was run on the Jolt machine. The left side (containing arms #1 thru #4) was set-up according to MIL-STD-331 with wood arms in good condition, a new leather pad and an existing wood anvil. The right side (containing arms #5 thru #8) was set-up with the substitute materials. That is, the two fabricated nylon arms were put in the #5 and #8 locations. A new polyurethane pad was used along with an existing wood anvil. To maintain uniformity only two wood arms, #1 and #4 were used. Arms in the location of #2, 3, 5 and 7 were placed in an inactive condition. An endurance test was then run for 300 hours, equivalent to more than 350 jolt tests (more than 600,000 shocks at approximately 200 g's, 2 ms.).

After 300 hours the components, including standard and substitute materials, were inspected. There was no visable damage to the wood arms or nylon arms. There was practically no change to the wood anvils. There was, however, a significant difference between the impact pads. The leather pad had been worn such that under ordinary test conditions, it would have been replaced before the 300 hours had expired. However, the polyurethane pad showed no signs of wearing in the impact areas.

The Jolt machine was then put back in the original condition used to measure the substitute material jolt environment. That is, arm #1 was replaced with the nylon arm which had occupied the #5 location in the endurance test. This had been the nylon arm on which previous acceleration data had been obtained. The worn leather pad on the left side was replaced with the polyurethane pad used on the right side in the 300 hour test. The wood anvil was not changed. All this changing around of the Jolt machine components was done to insure that any changes to the jolt environment could be attributed to the long term effects of the endurance test. Dummy test fixtures were then placed into the nylon jolt arm, and accelerometers were bonded in the "nose-up" and "fuze axis horizontal" positions. The same instrumentation system as before was then used to measure 30 jolts. In looking at the time histories and shock spectra signatures of the conditions before and after 300 hours of testing, there were no significant differences found in the substitute material's jolt environment.

APPENDIX B

JOLT MACHINE TIME HISTORIES

This appendix includes the following curves referred to in the report under the Jolt test subproject.

JOLT MACHINE TIME HISTORIES

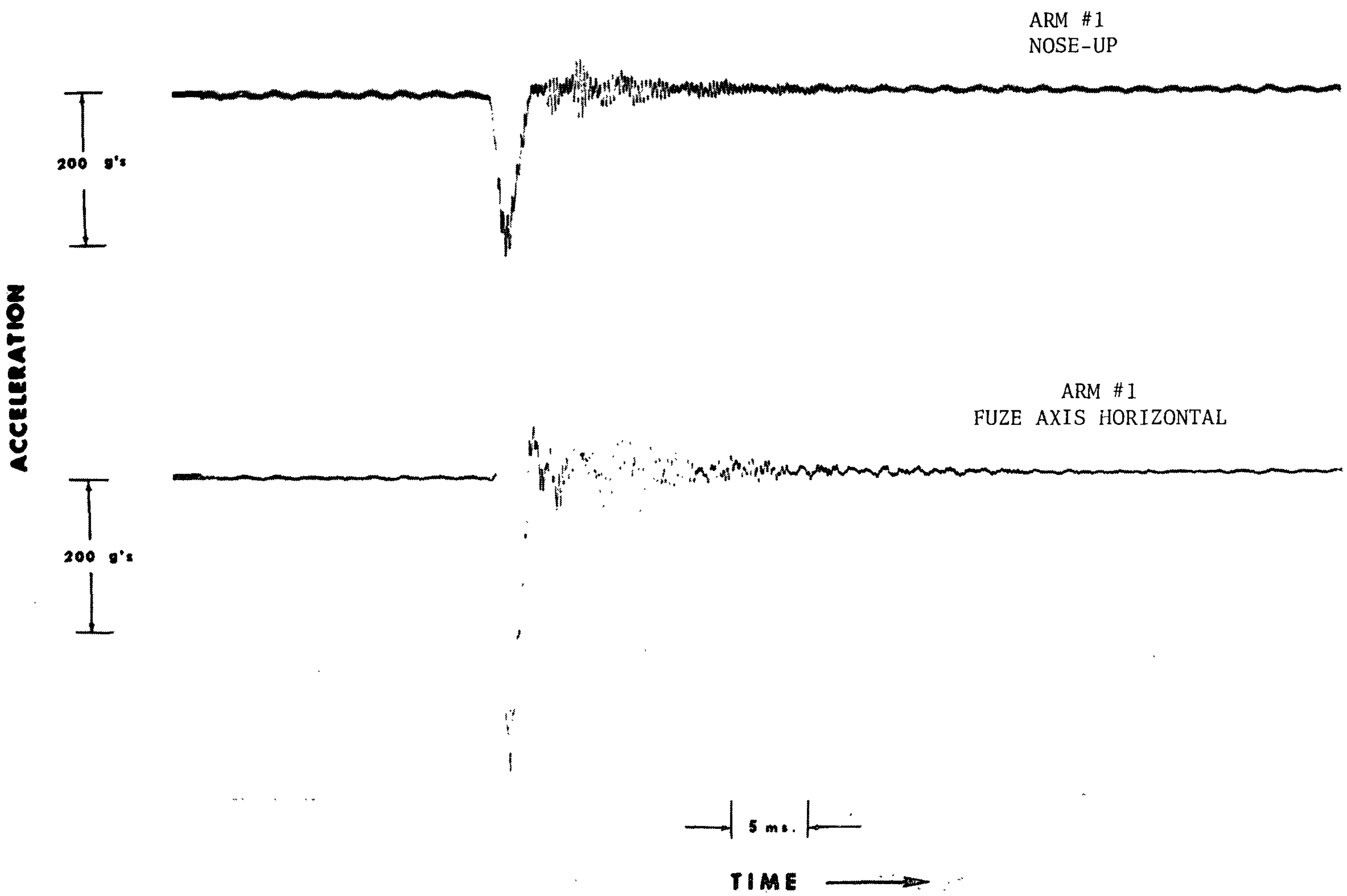


Figure B-1. Arm #1, 9 lb. Test Load, 4 Arms Active, Standard Materials, Nose-Up and Fuze Axis Horizontal

JOLT MACHINE TIME HISTORIES

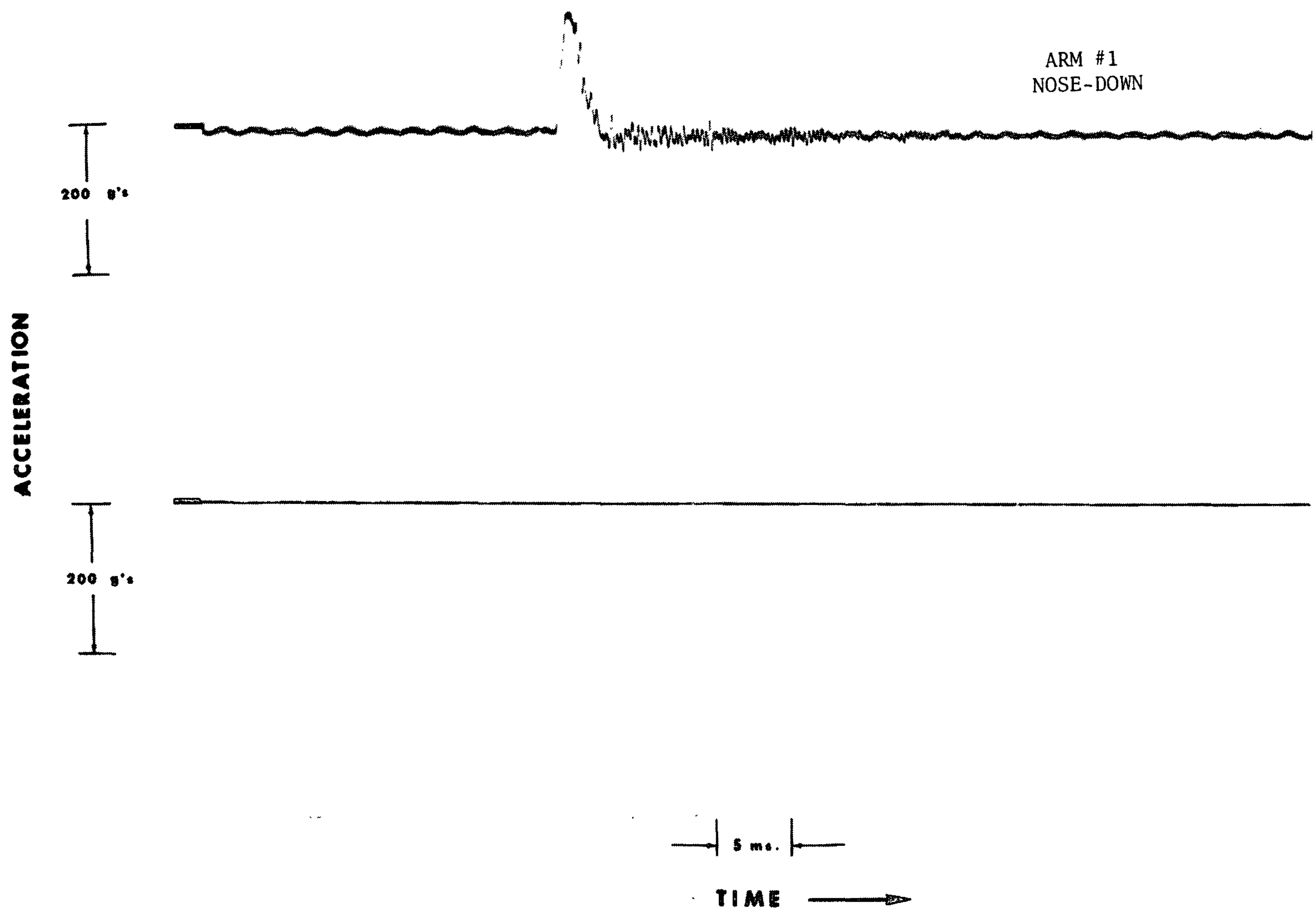


Figure B-2. Arm #1, 9 lb. Test Load, 4 Arms Active, Standard Materials, Nose-Down

JOLT MACHINE TIME HISTORIES

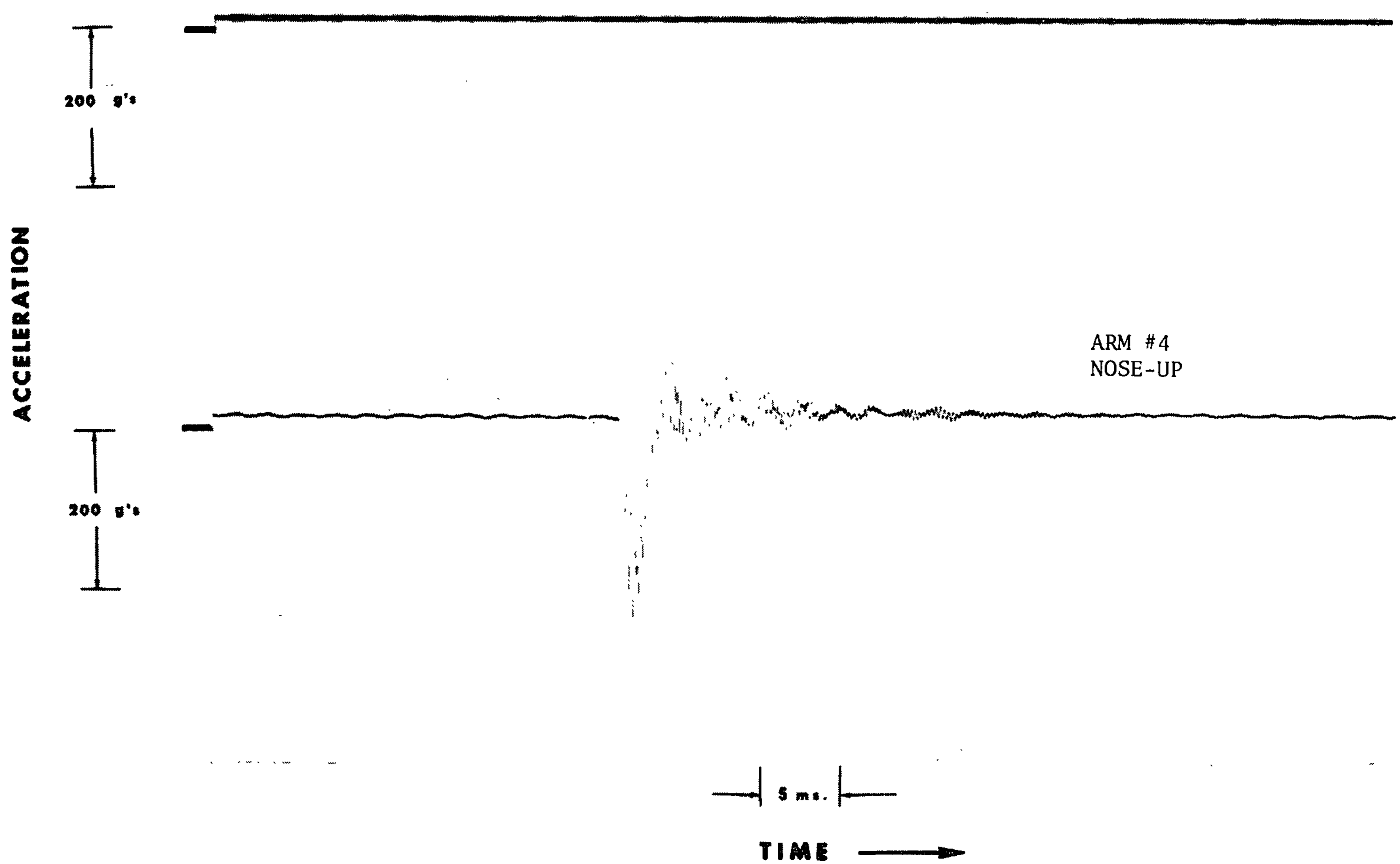


Figure B-3. Arm #4, Nose-Up

JOLT MACHINE TIME HISTORIES

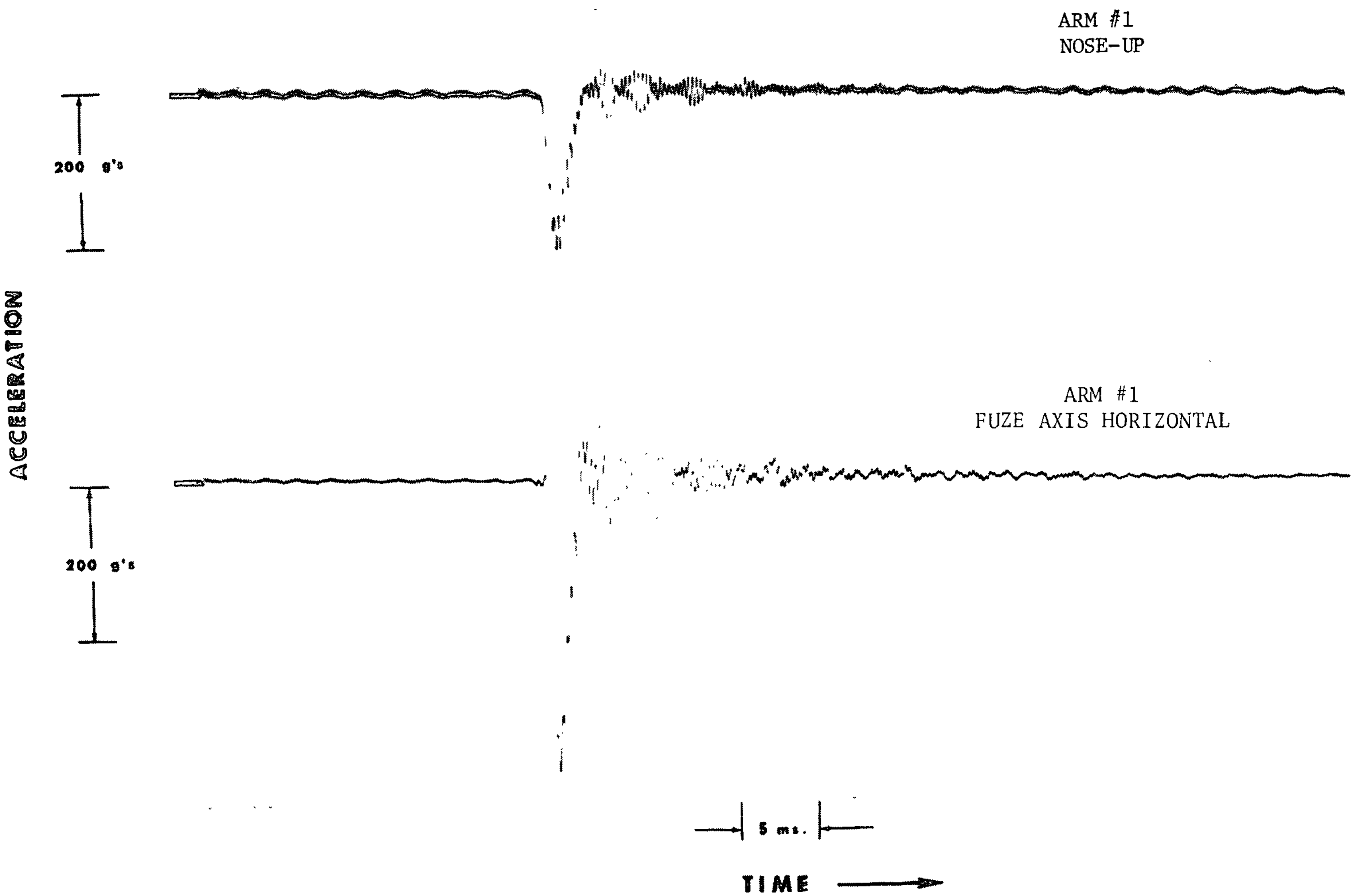


Figure B-4. One Arm Active, Nose-Up and Fuze Axis Horizontal

JOLT MACHINE TIME HISTORIES

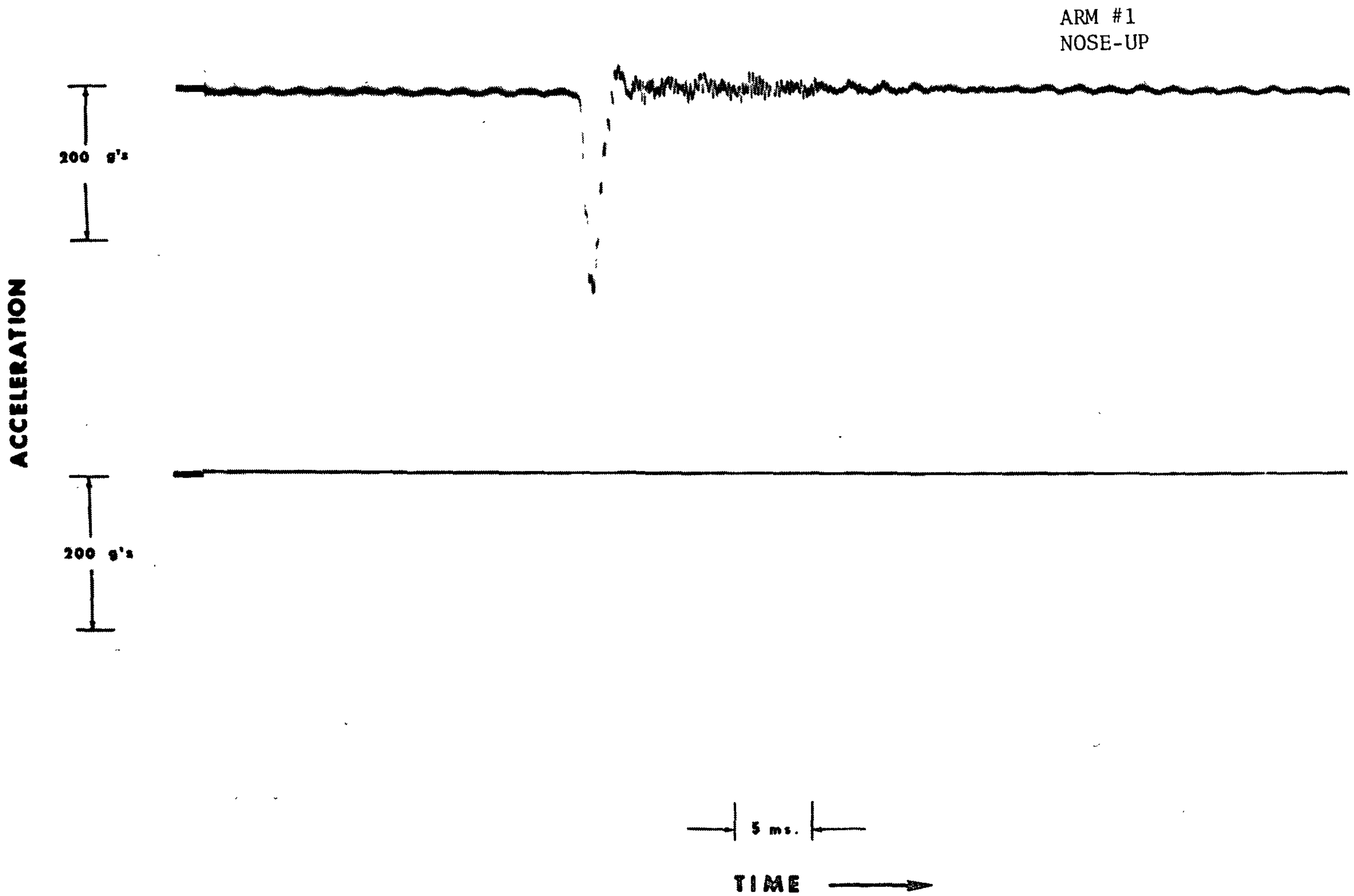


Figure B-5. 3 lb. Test Load, Nose-Up

JOLT MACHINE TIME HISTORIES

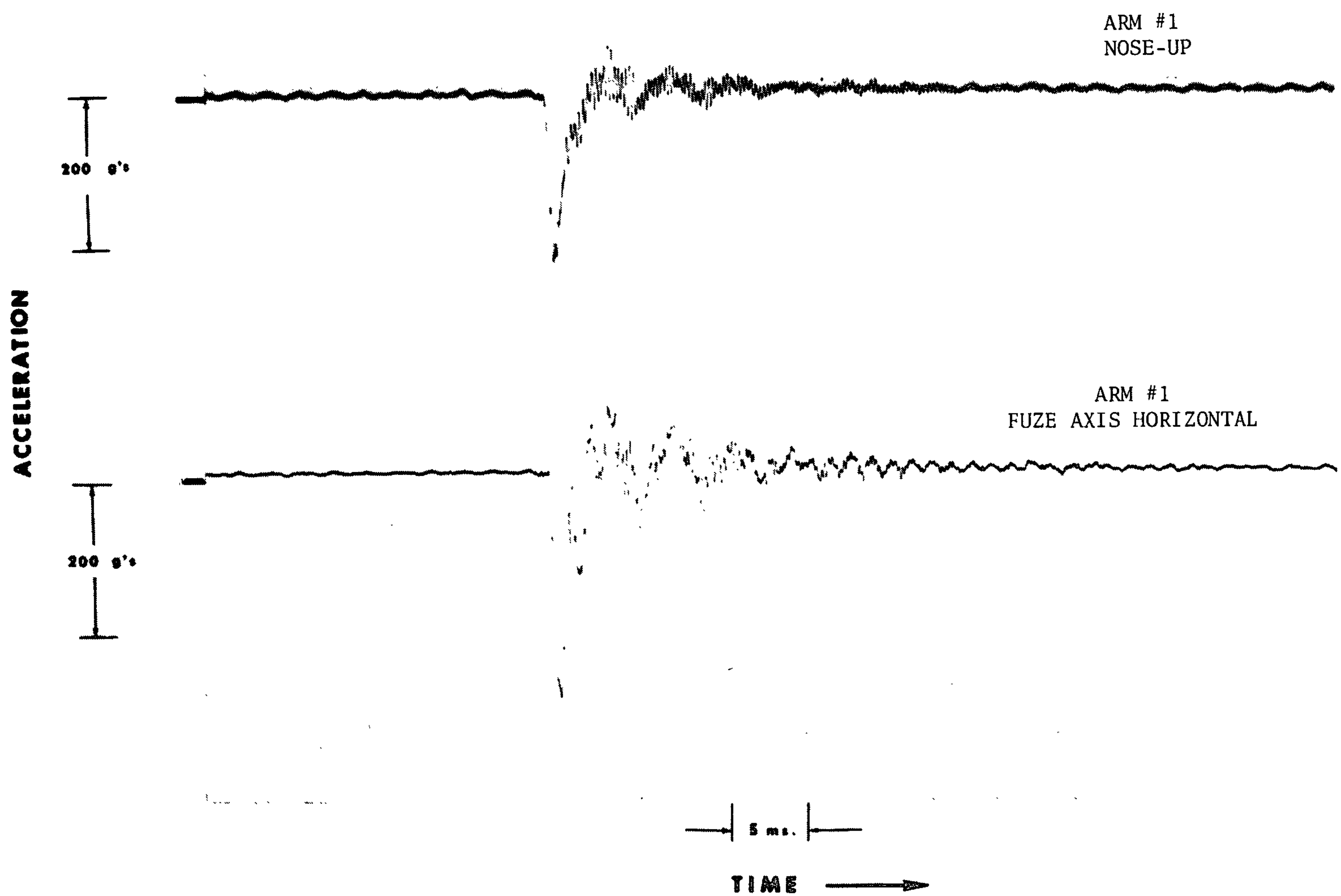


Figure B-6. Nylon Arm, Nose-Up and Fuze Axis Horizontal

JOLT MACHINE TIME HISTORIES

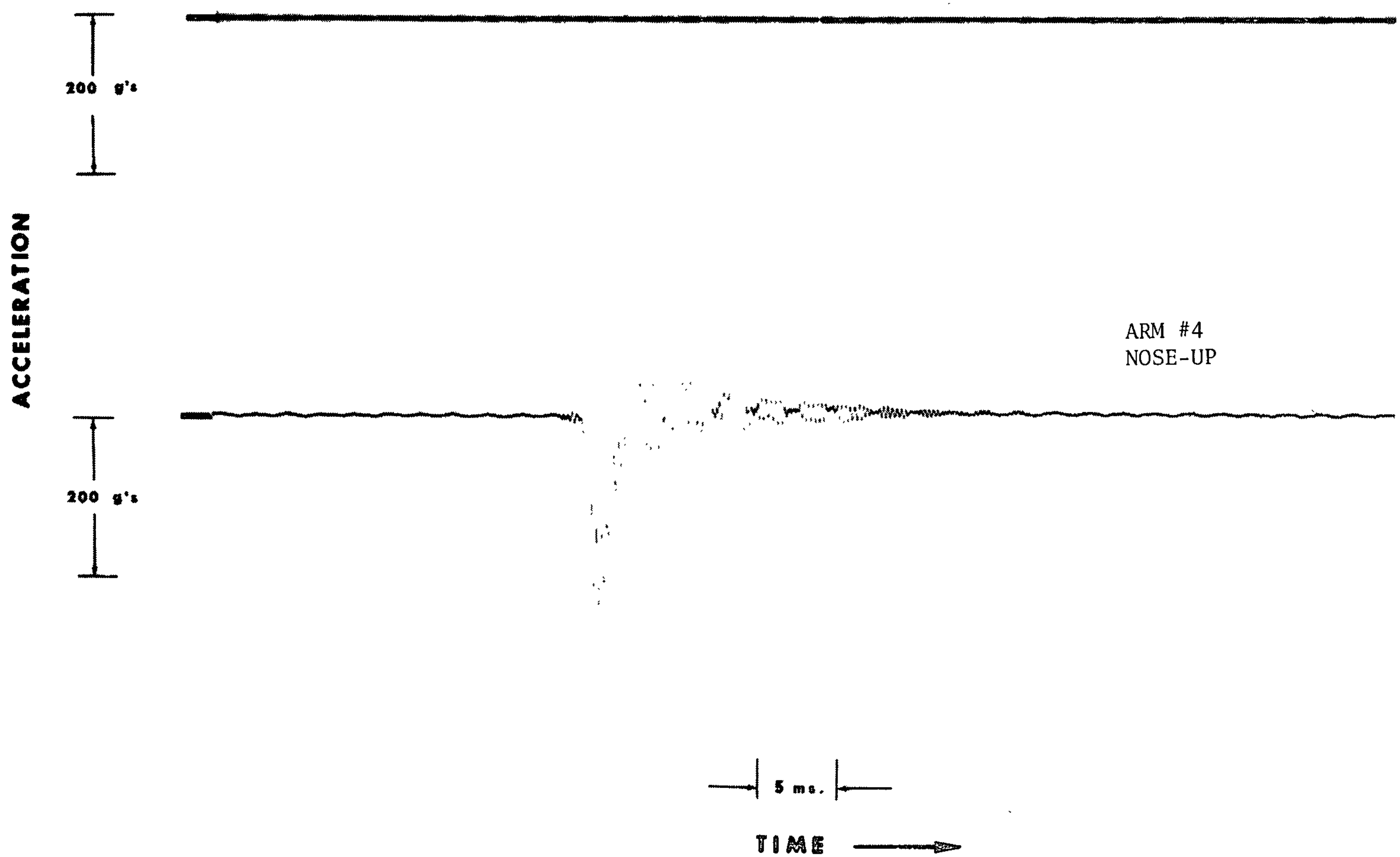


Figure B-7. Polyurethane Pad, Nose-Up

JOLT MACHINE TIME HISTORIES

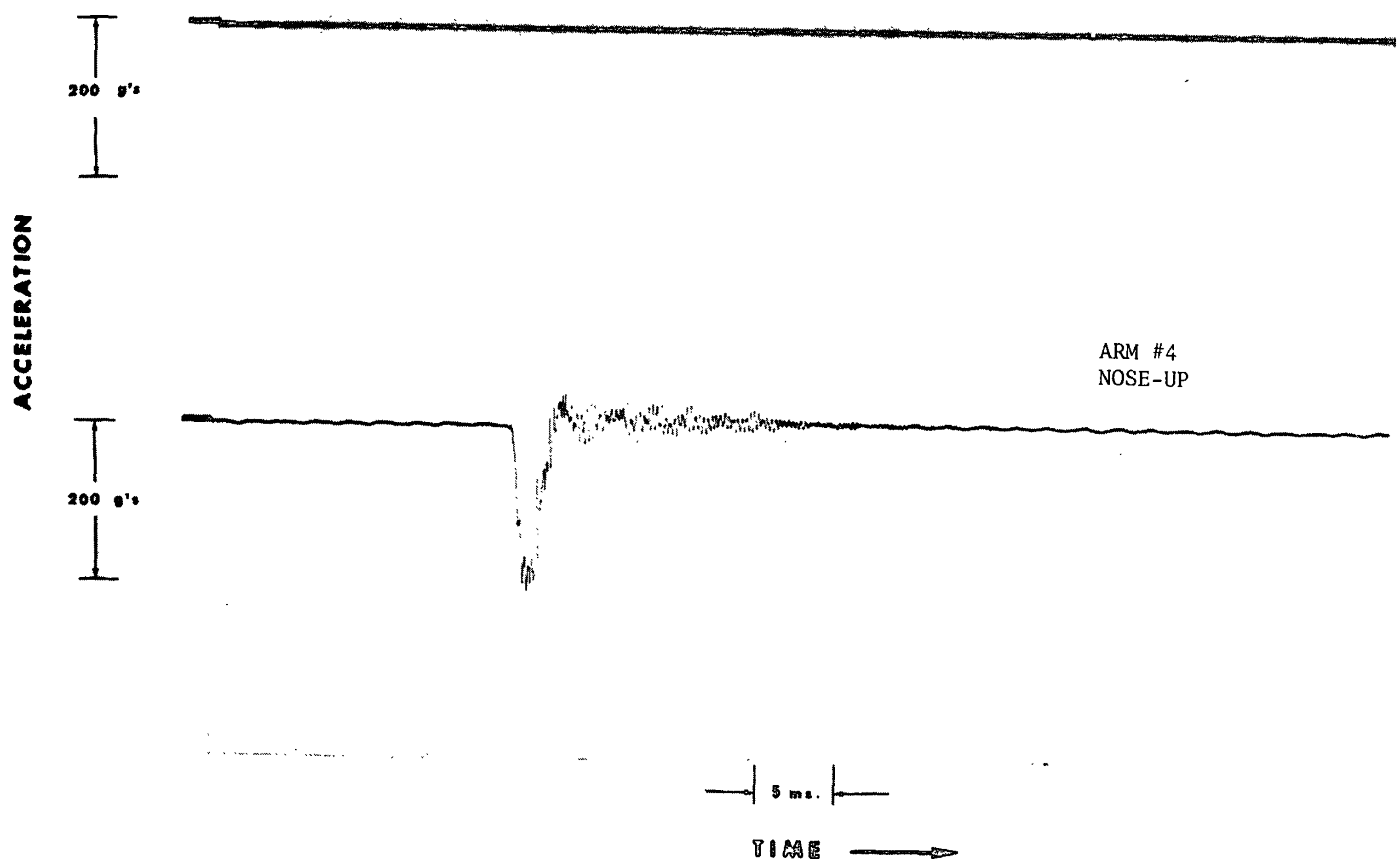


Figure B-8. Nylon Anvil, Nose-Up

JOLT MACHINE TIME HISTORIES

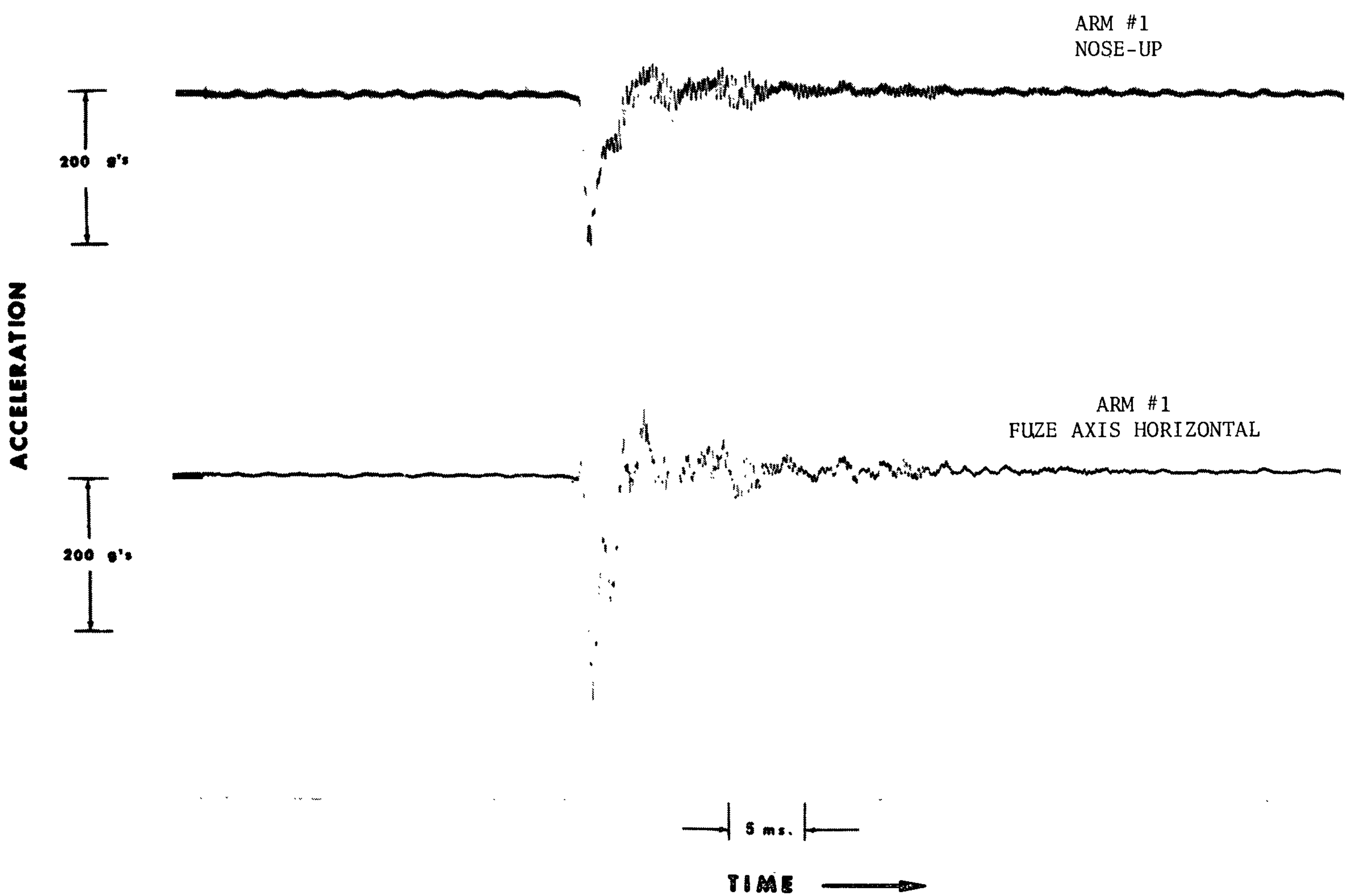


Figure B-9. Nylon Arm and Polyurethane Pad, Nose-Up and Fuze Axis Horizontal

JOLT MACHINE TIME HISTORIES

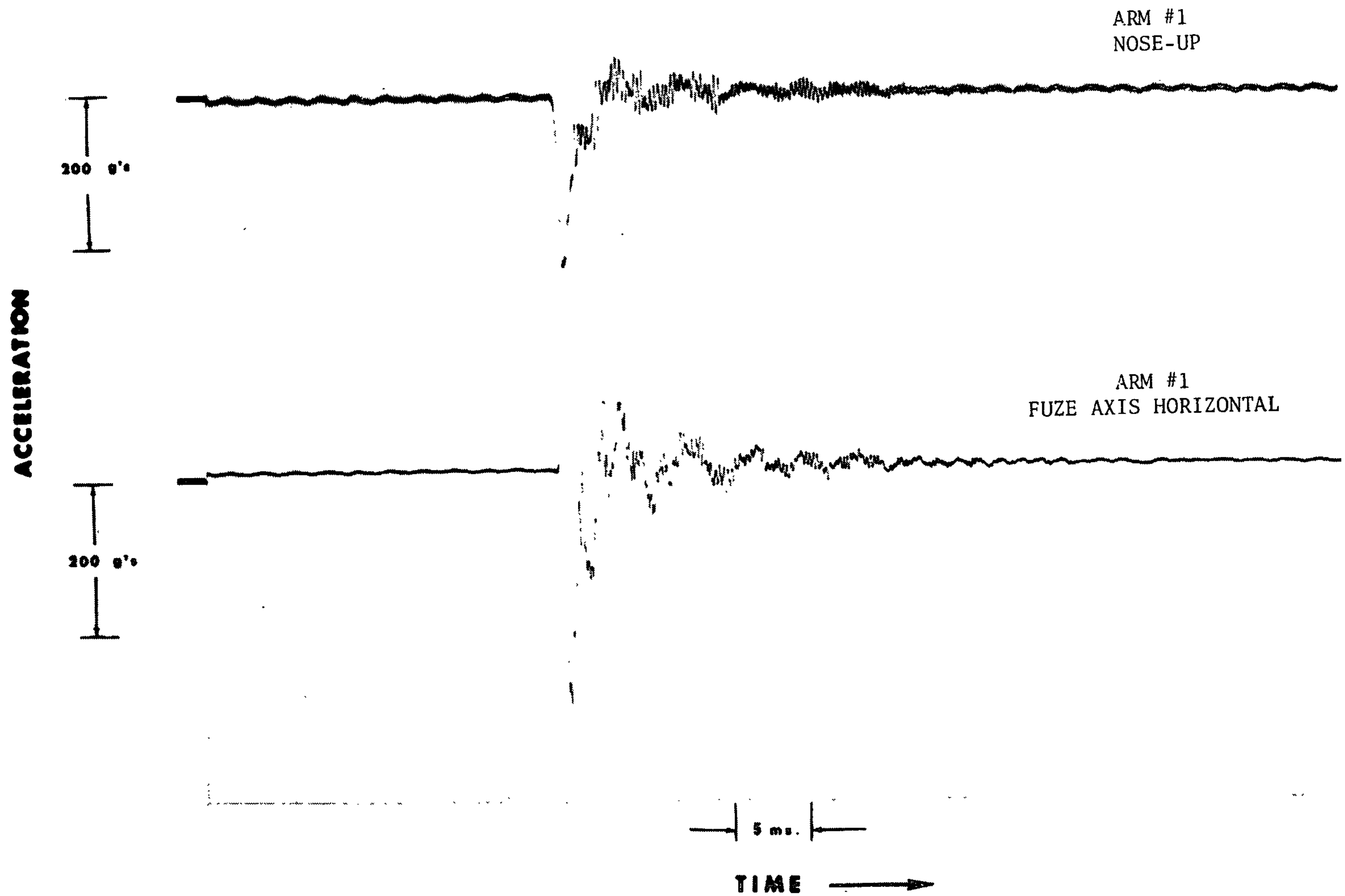


Figure B-10. Nylon Arm and Nylon Anvil, Nose-Up and Fuze Axis Horizontal

JOLT MACHINE TIME HISTORIES

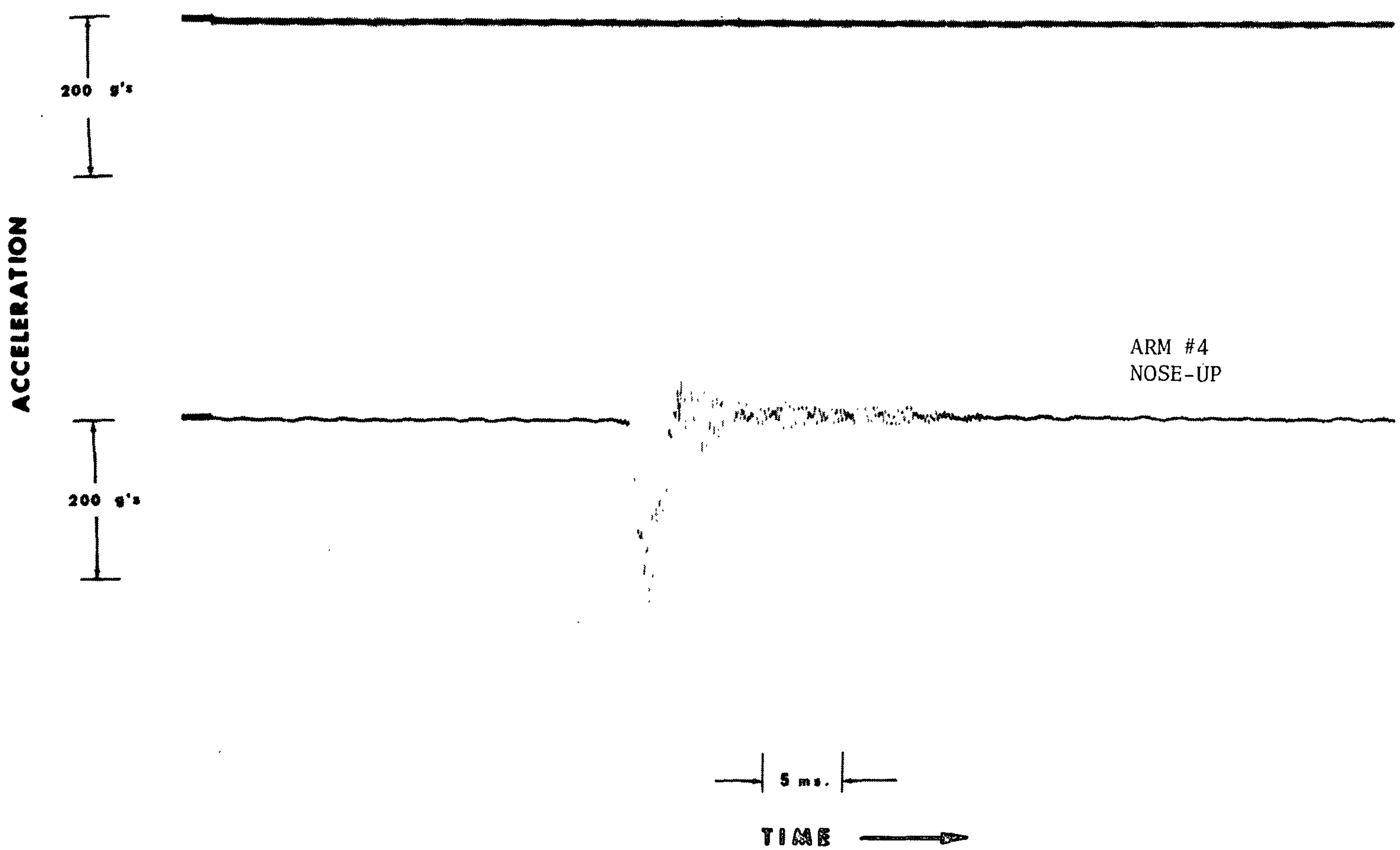


Figure B-11. Polyurethane Pad and Nylon Anvil, Nose-Up

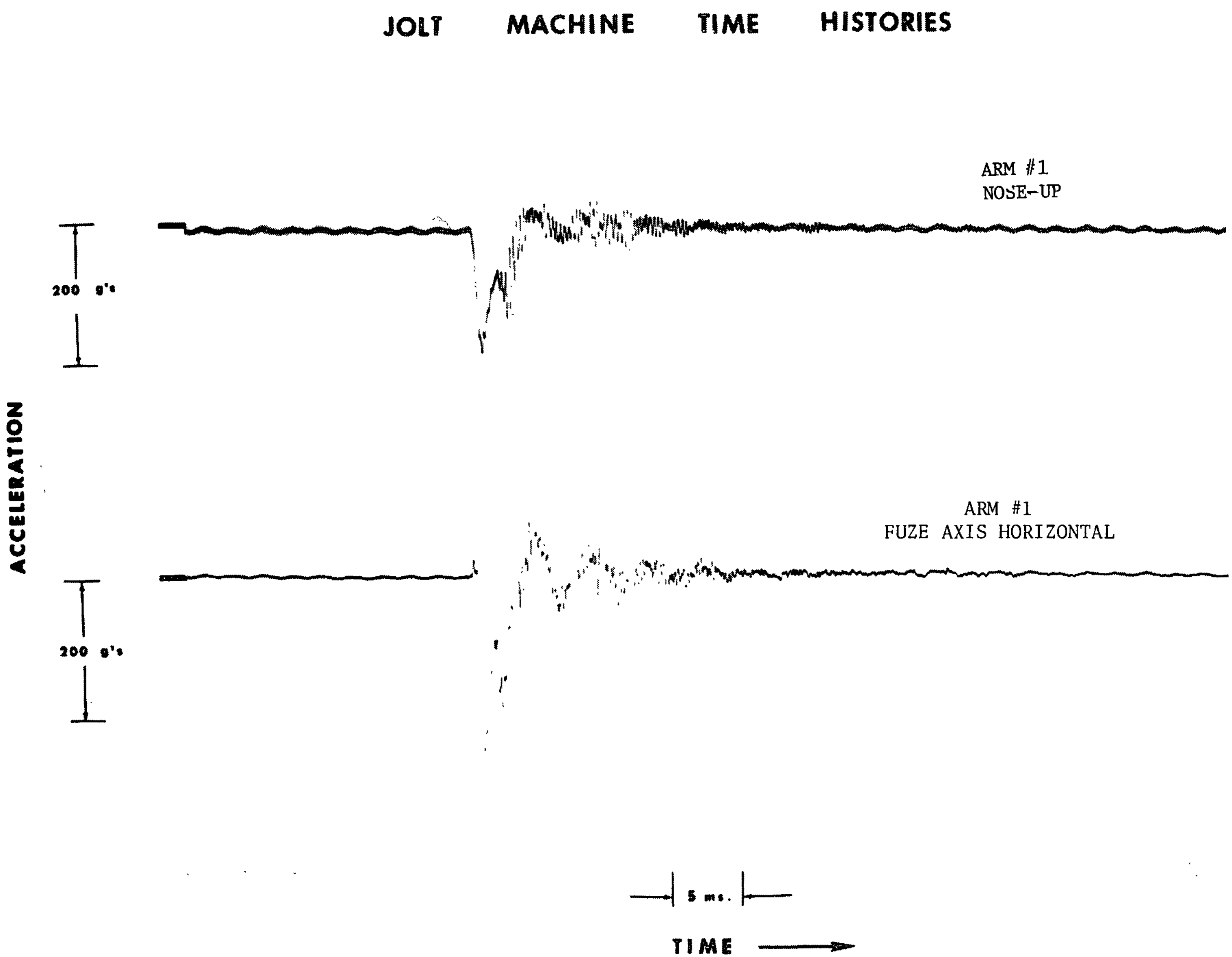


Figure B-12. Nylon Arm, Polyurethane Pad, Nylon Anvil, Nose-Up and Fuze Axis Horizontal

APPENDIX C

JOLT MACHINE SHOCK SPECTRA

This Appendix includes curves referred to in the Jolt Test subproject Section of this report.

JOLT MACHINE SHOCK SPECTRA

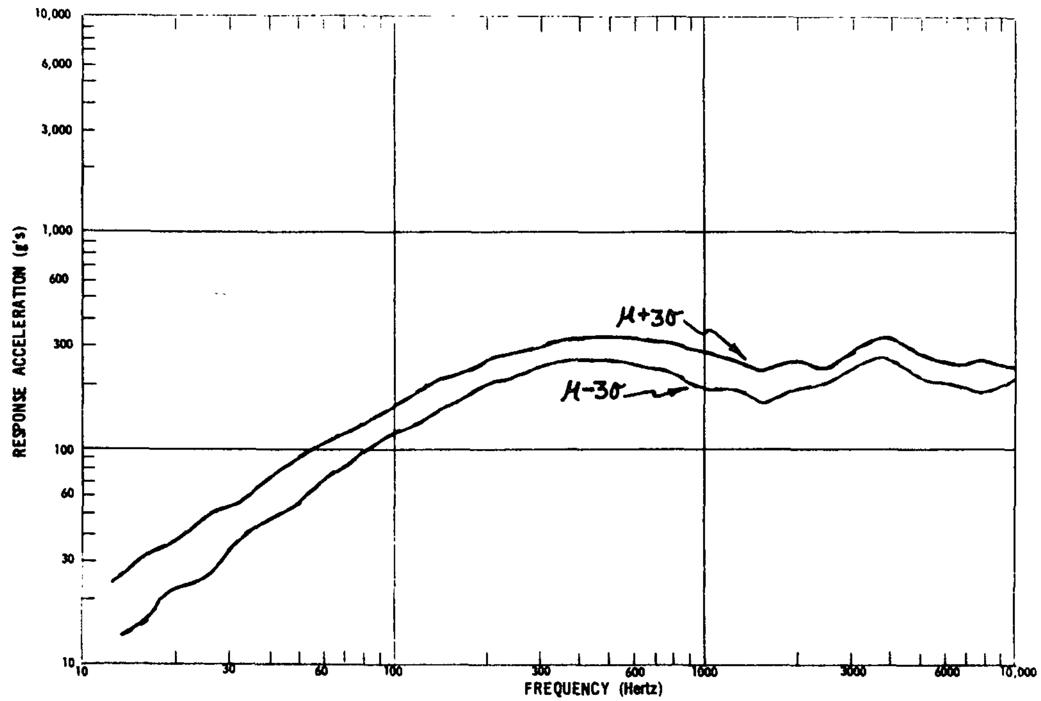


Figure C-1. Standard Jolt Environment (μ±3σ Based on 30 Jolt Shocks from Arm #1, 9 lb. Test Load, Nose-Up, 4 Arms Active, Wood Arm, Leather Pad, Wood Anvil)

JOLT MACHINE SHOCK SPECTRA

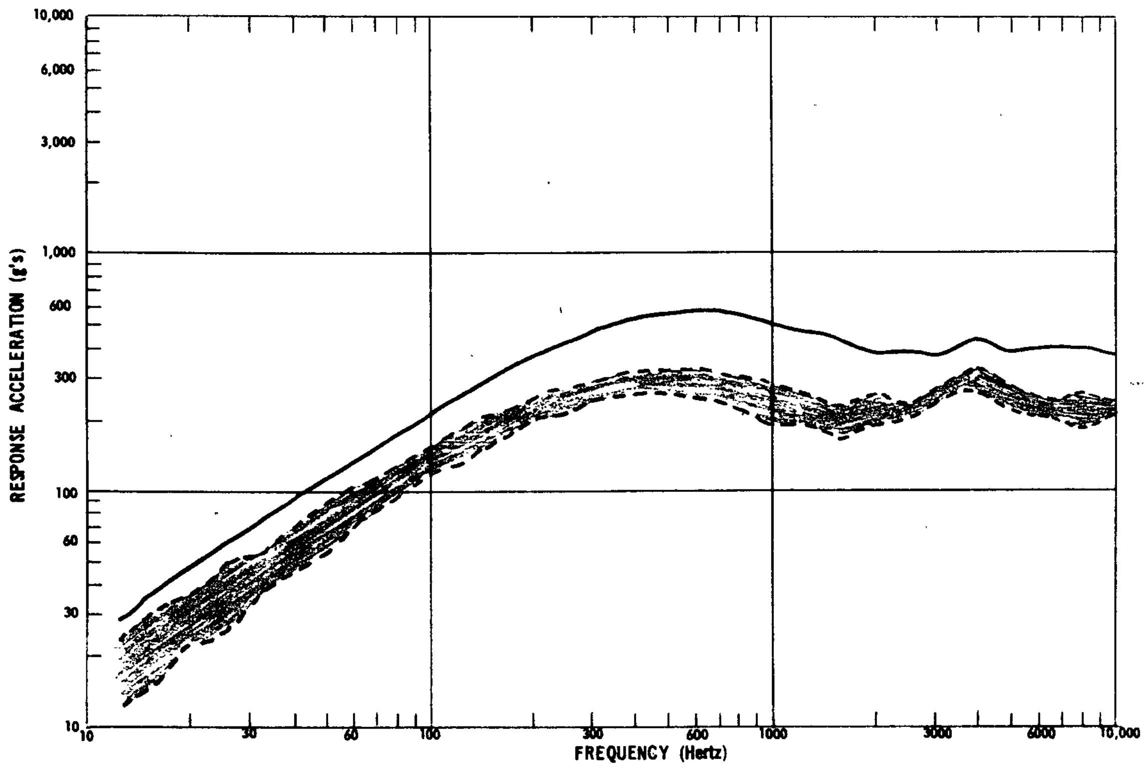


Figure C-2. Fuze Axis Horizontal vs Standard Jolt Environment (Solid Line vs $\mu \pm 3\sigma$)

JOLT MACHINE SHOCK SPECTRA

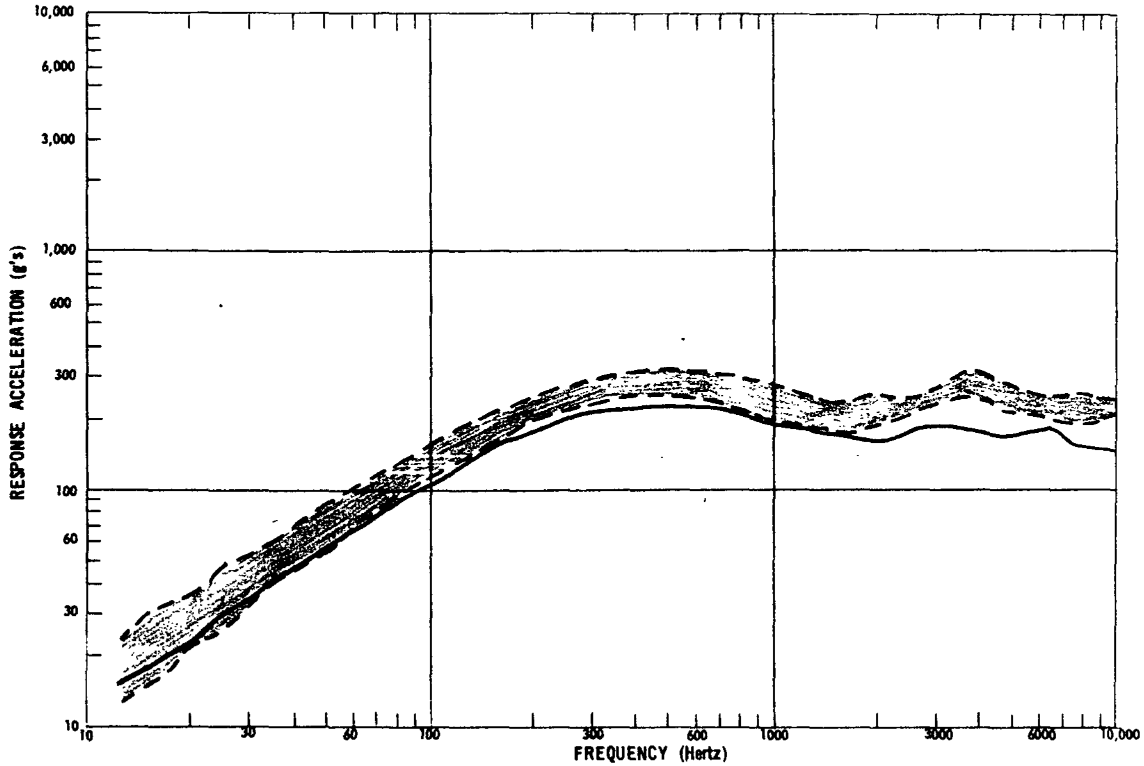


Figure C-3. Nose-Down vs Standard Jolt Environment (Solid Line vs $\mu \pm 3\sigma$)

JOLT MACHINE SHOCK SPECTRA

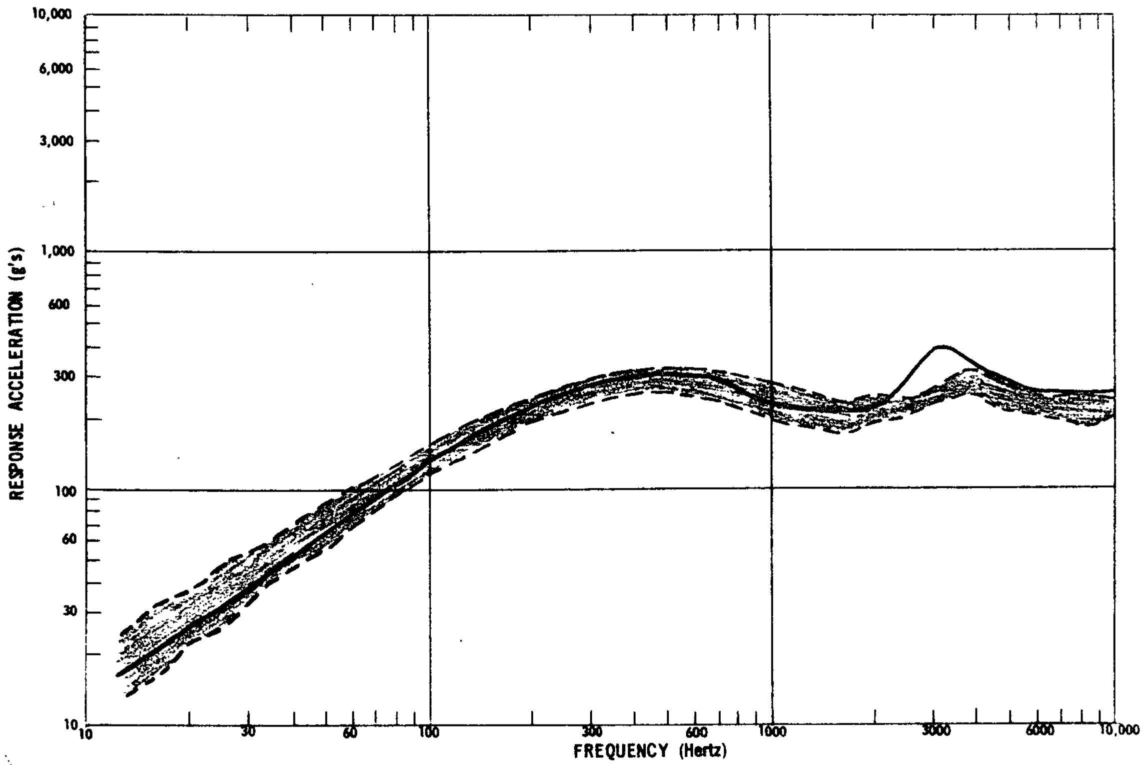


Figure C-4. Arm #4 vs Standard Jolt Environment (Solid Line vs μ±3σ)

JOLT MACHINE SHOCK SPECTRA

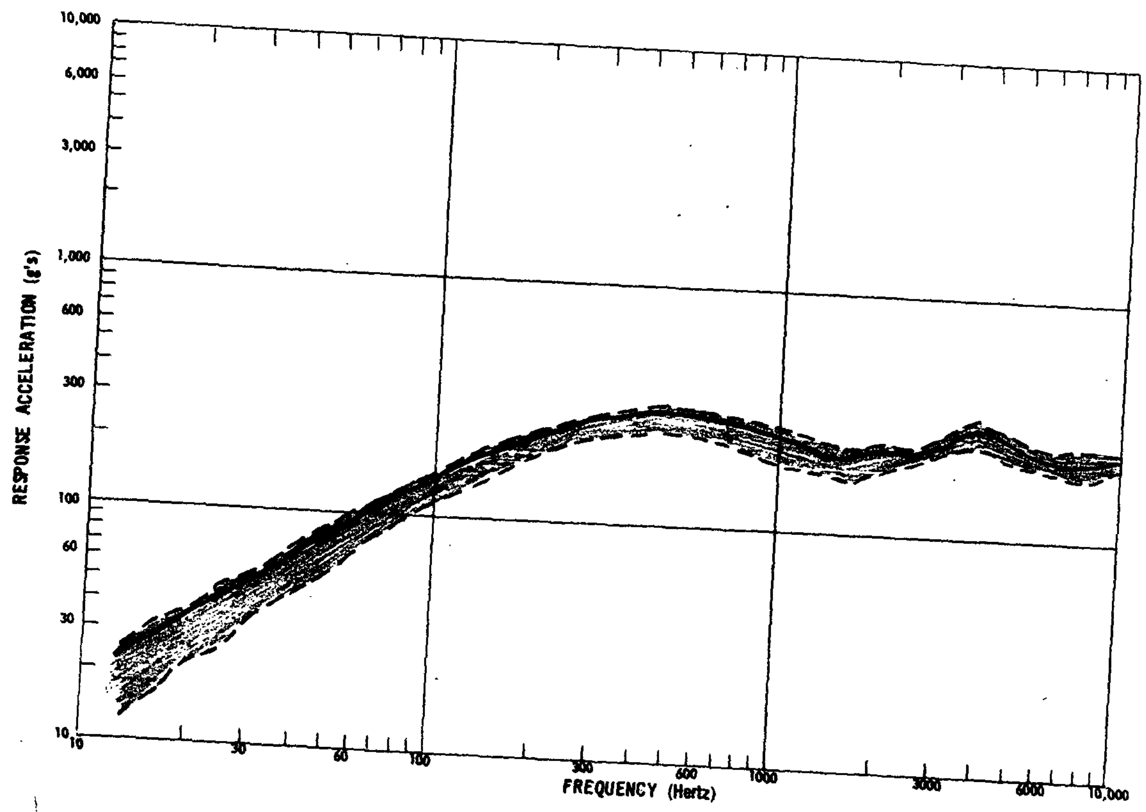


Figure C-5. One Arm Active vs Standard Jolt Environment (Solid Line vs $\mu \pm 3\sigma$)

JOLT MACHINE SHOCK SPECTRA

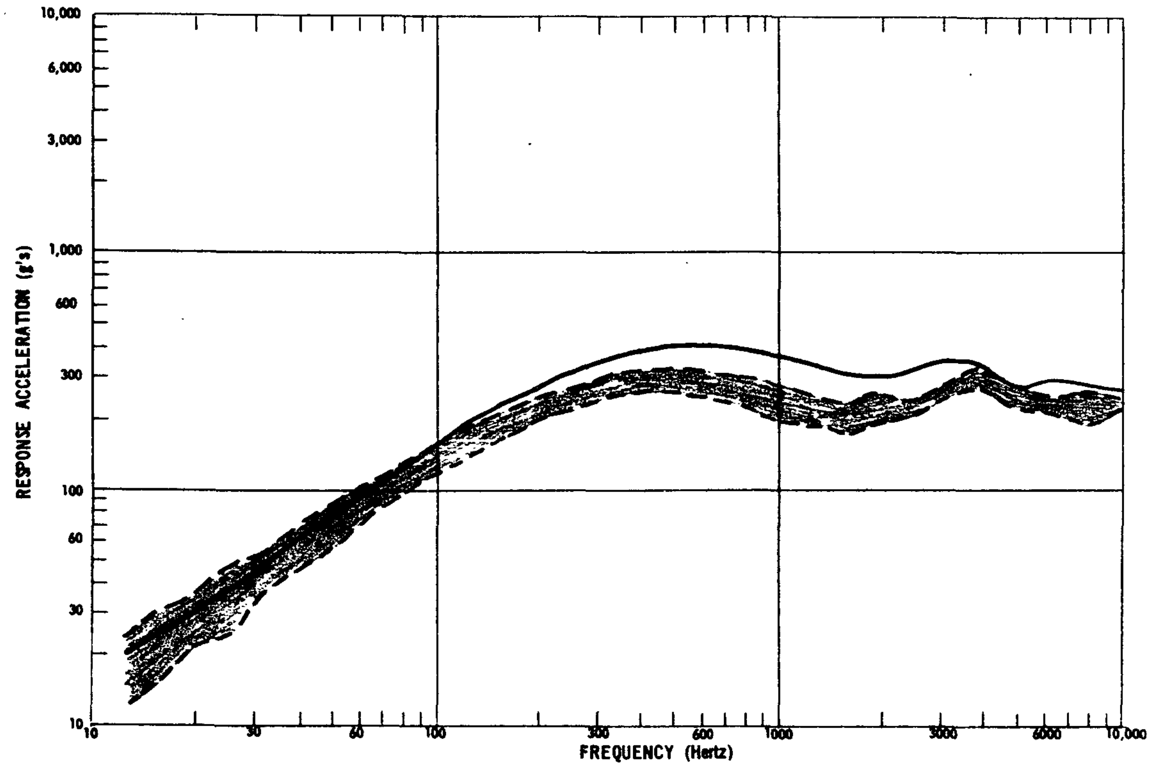


Figure C-6. 3 lb. Test Load vs Standard Jolt Environment (Solid Line vs $\mu \pm 3\sigma$)

JOLT MACHINE SHOCK SPECTRA

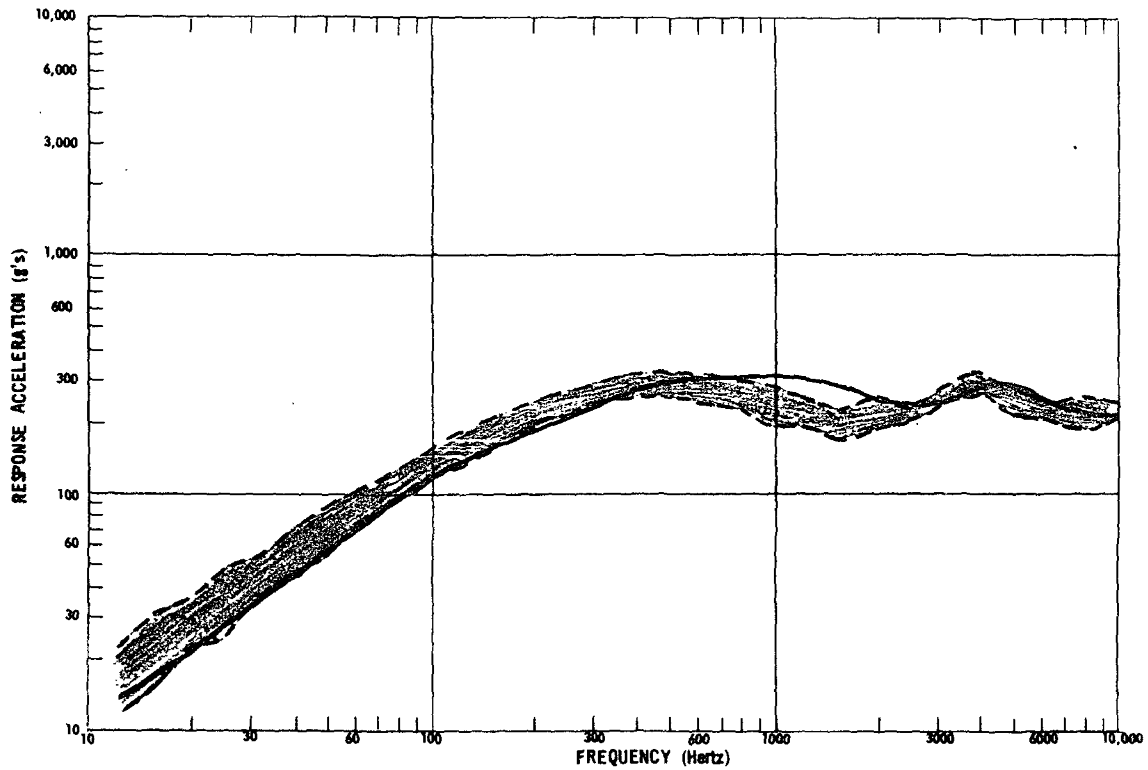


Figure C-7. Nylon Arm vs Standard Jolt Environment (Solid Line vs $\mu \pm 3\sigma$)

JOLT MACHINE SHOCK SPECTRA

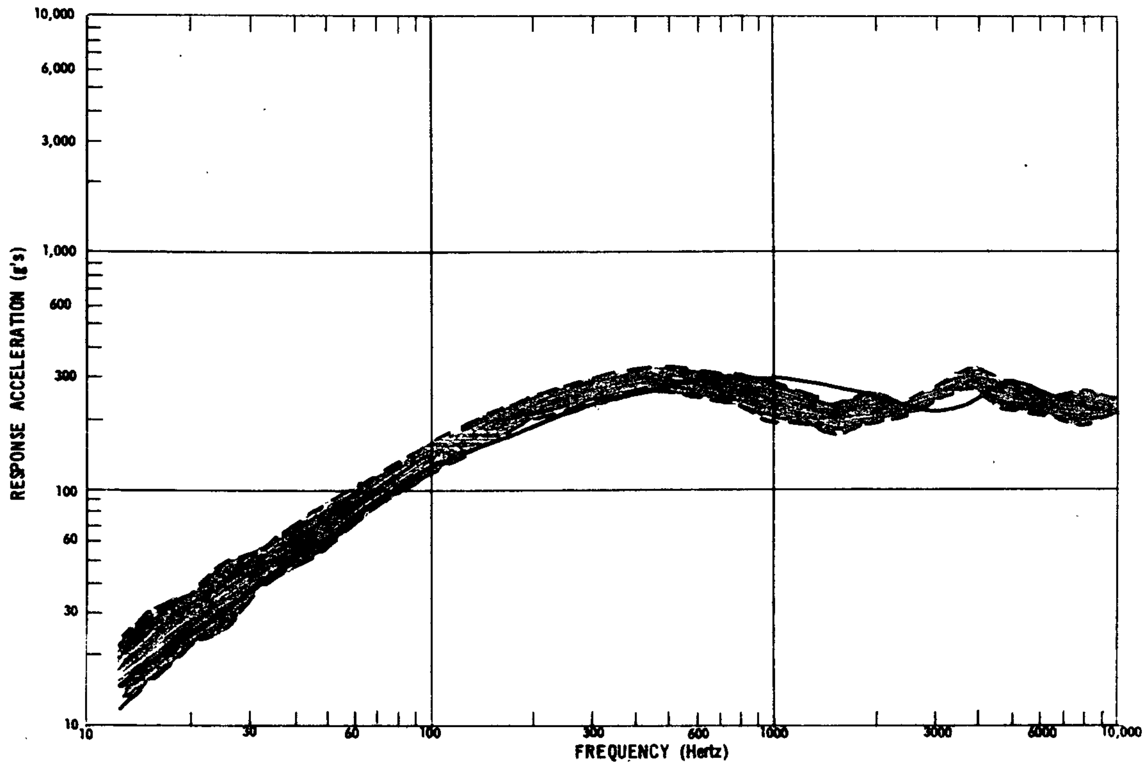


Figure C-8. Nylon Arm and Polyurethane Pad vs Standard Jolt Environment (Solid Line vs μ±3σ)

JOLT MACHINE SHOCK SPECTRA

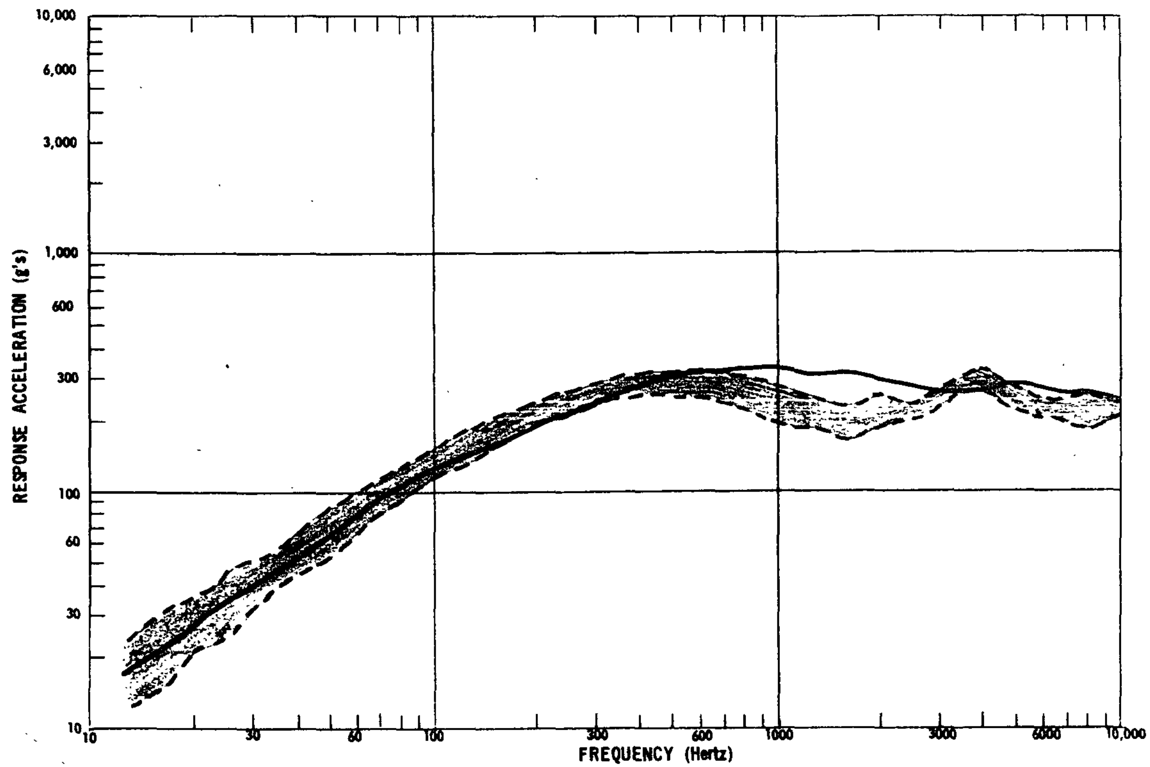


Figure C-9. Nylon Arm and Nylon Anvil vs Standard Jolt Environment (Solid Line vs $\mu \pm 3\sigma$)

JOLT MACHINE SHOCK SPECTRA

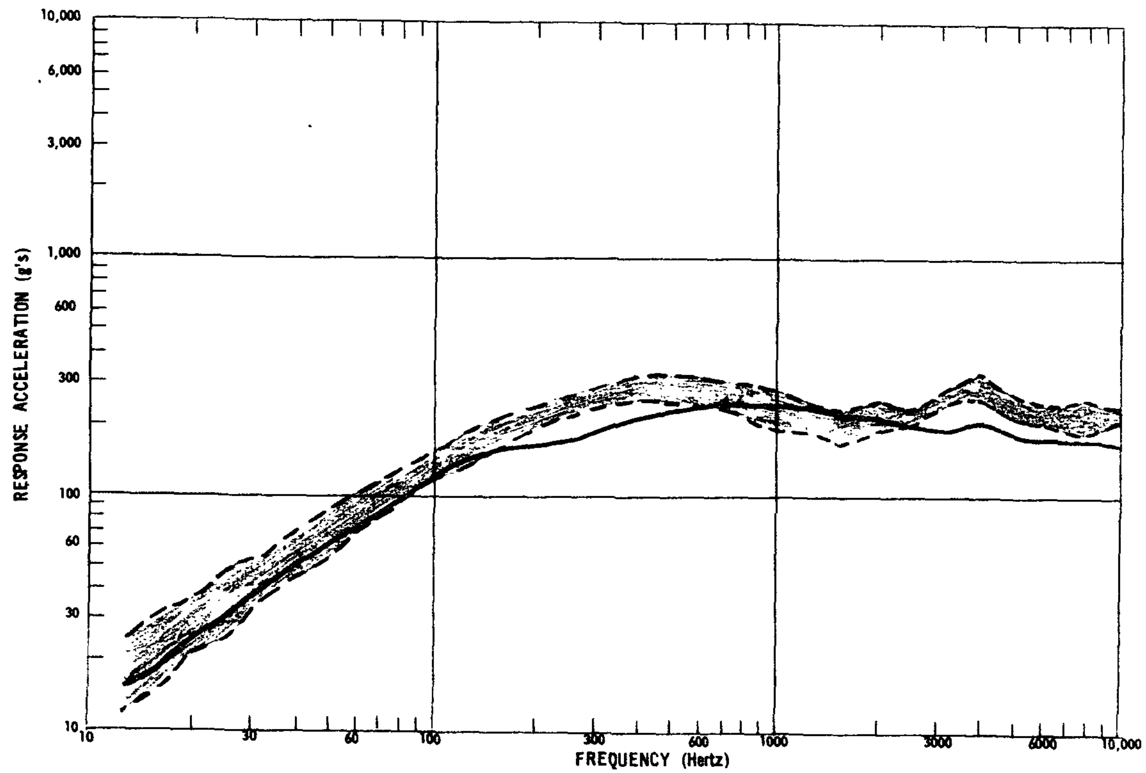


Figure C-10. Nylon Arm, Polyurethane Pad and Nylon Anvil vs Standard Jolt Environment (Solid Line vs $\mu \pm 3\sigma$)

APPENDIX D

PENDULUM TEST SHOCK SPECTRA

This Appendix contains curves referred to in the Jumble test subproject section of this report.

PENDULUM TEST SHOCK SPECTRA

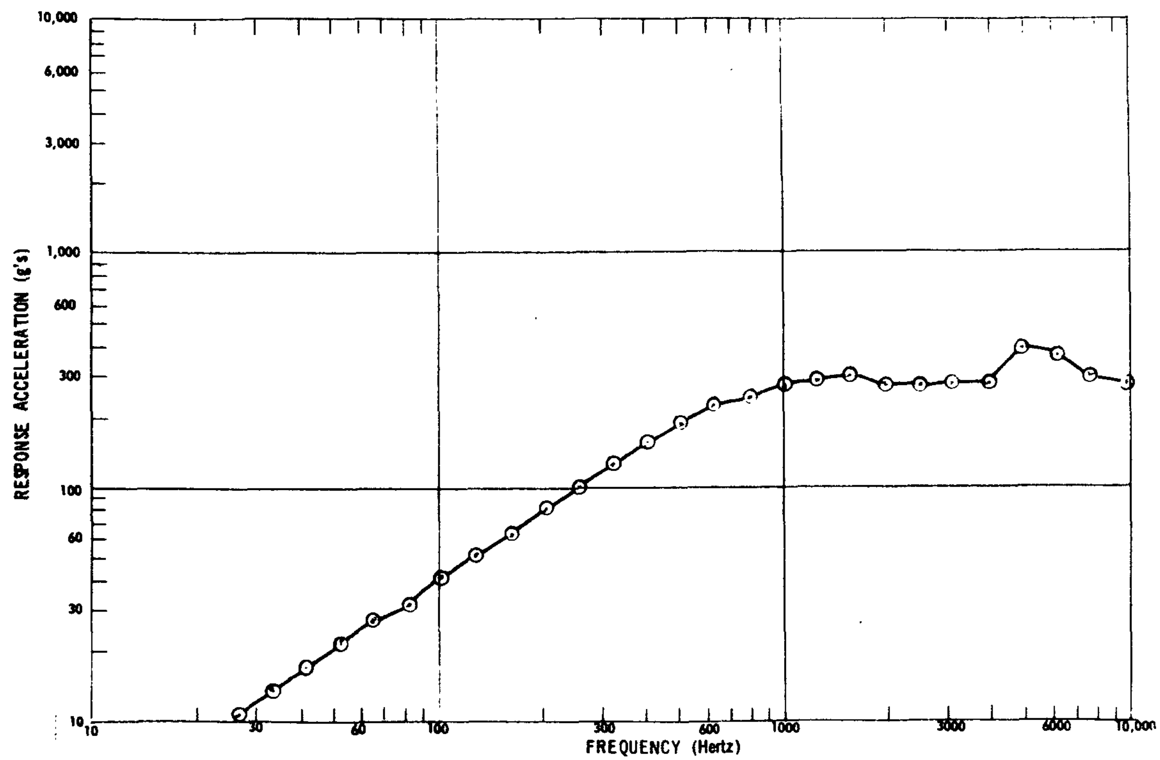


Figure D-1. Wood, 3/4" Thick, Nose Flat Impact, 5" Drop Height

PENDULUM TEST SHOCK SPECTRA

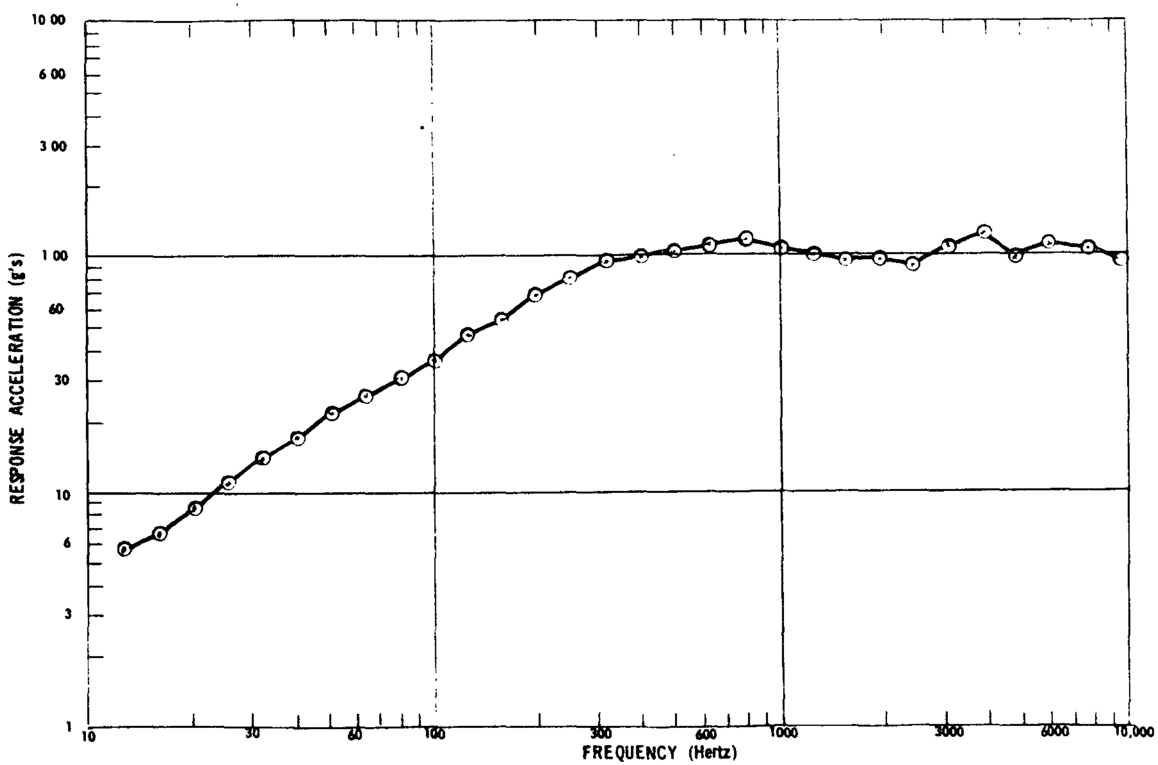


Figure D-2. Wood, 3/4" Thick, Nose Angle Impact, 5" Drop Height

PENDULUM TEST SHOCK SPECTRA

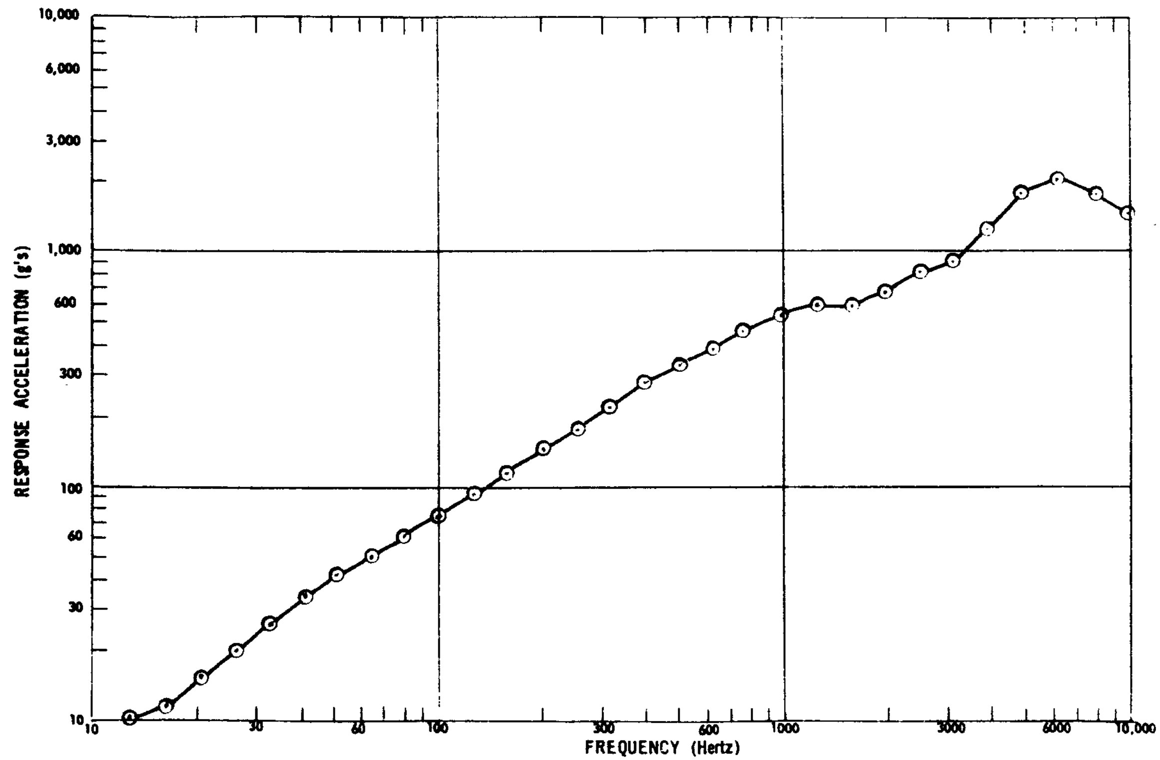


Figure D-3. Wood, 3/4" Thick, Nose Flat Impact, 5" Drop Height

PENDULUM TEST SHOCK SPECTRA

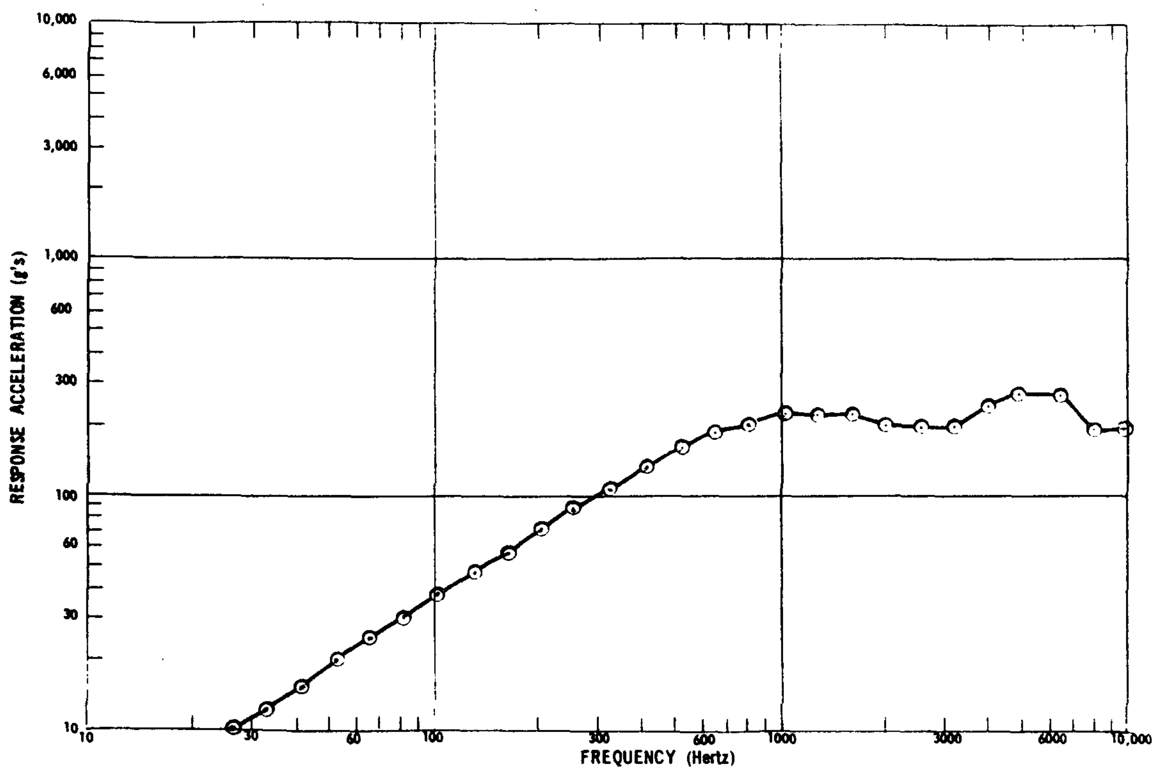


Figure D-4. Wood, 1/4" Thick, Nose Flat Impact, 5" Drop Height

PENDULUM TEST SHOCK SPECTRA

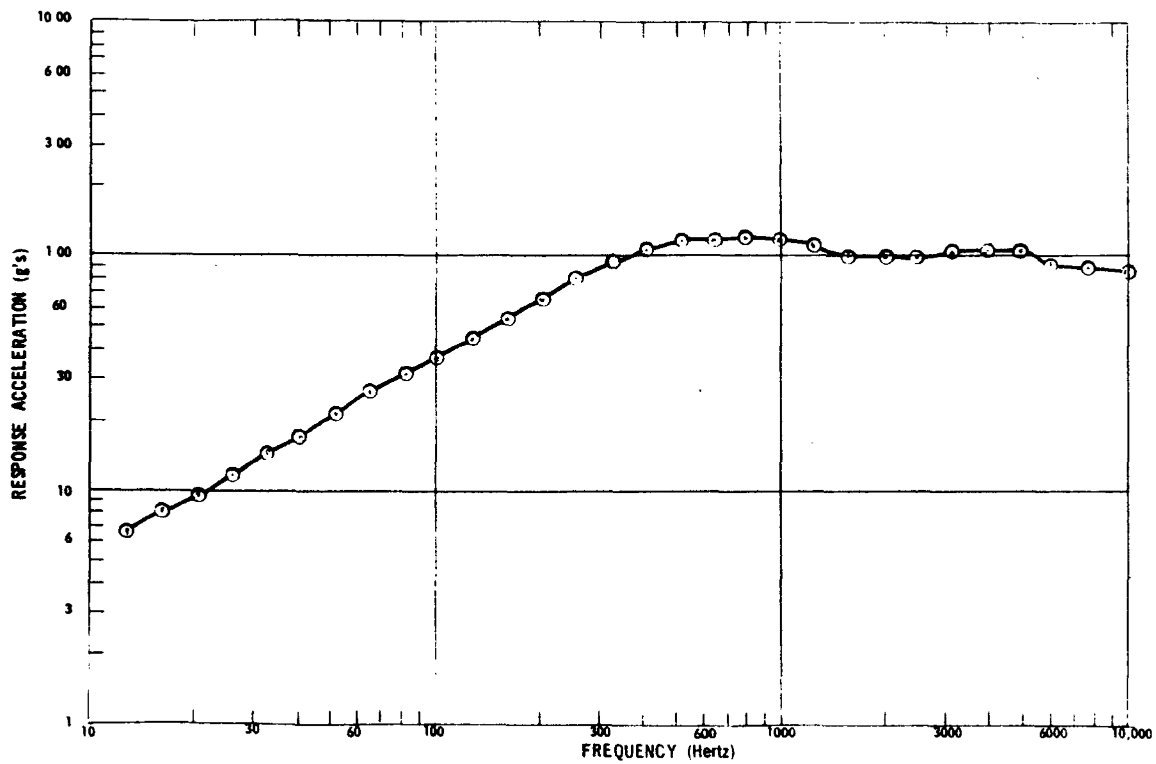


Figure D-5. Wood, 1/4" Thick, Nose Angle Impact, 5" Drop Height

PENDULUM TEST SHOCK SPECTRA

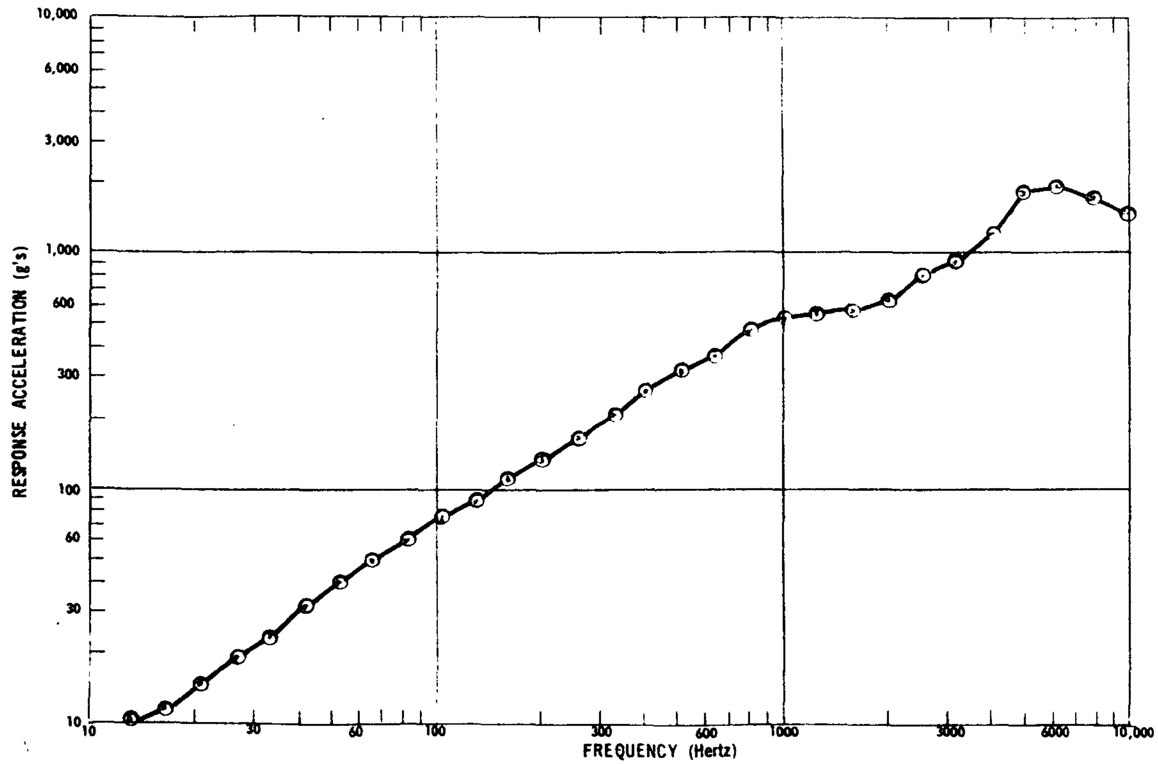


Figure D-6. Wood, 1/4" Thick, Nose Flat Impact, 10" Drop Height

PENDULUM TEST SHOCK SPECTRA

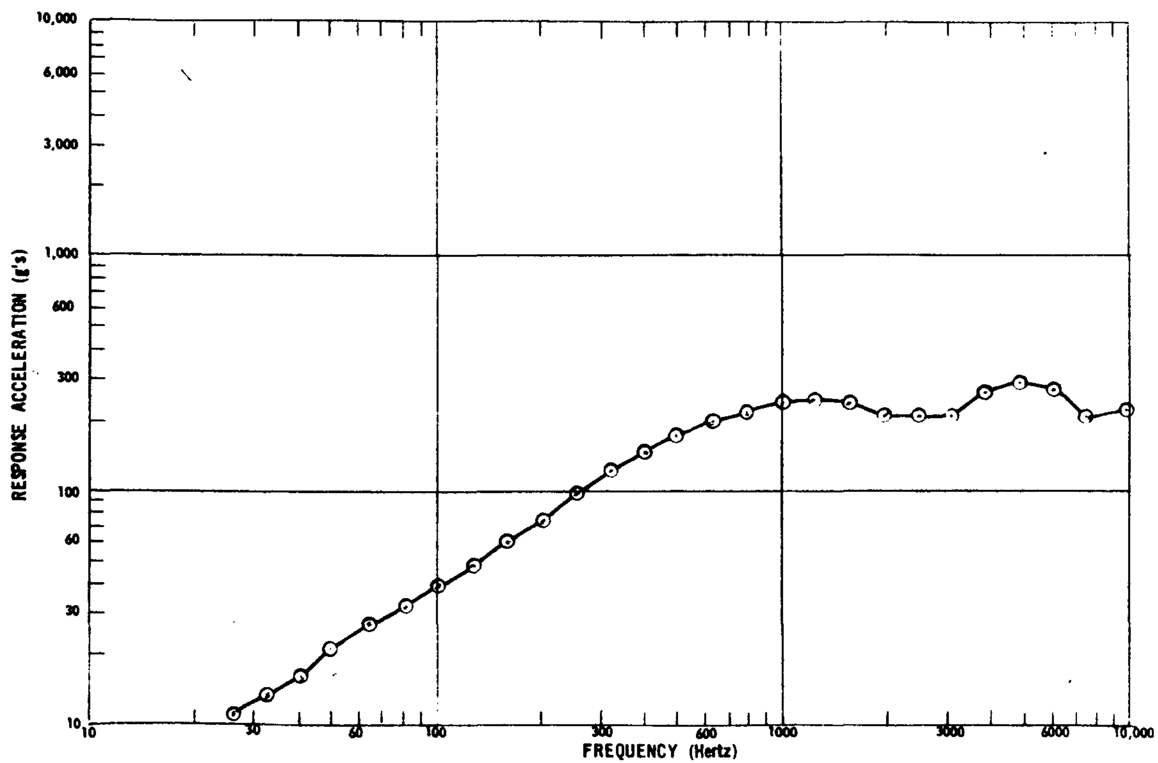


Figure D-7. Polyurethane, 3/4" Thick, Nose Flat Impact, 5" Drop Height

PENDULUM TEST SHOCK SPECTRA

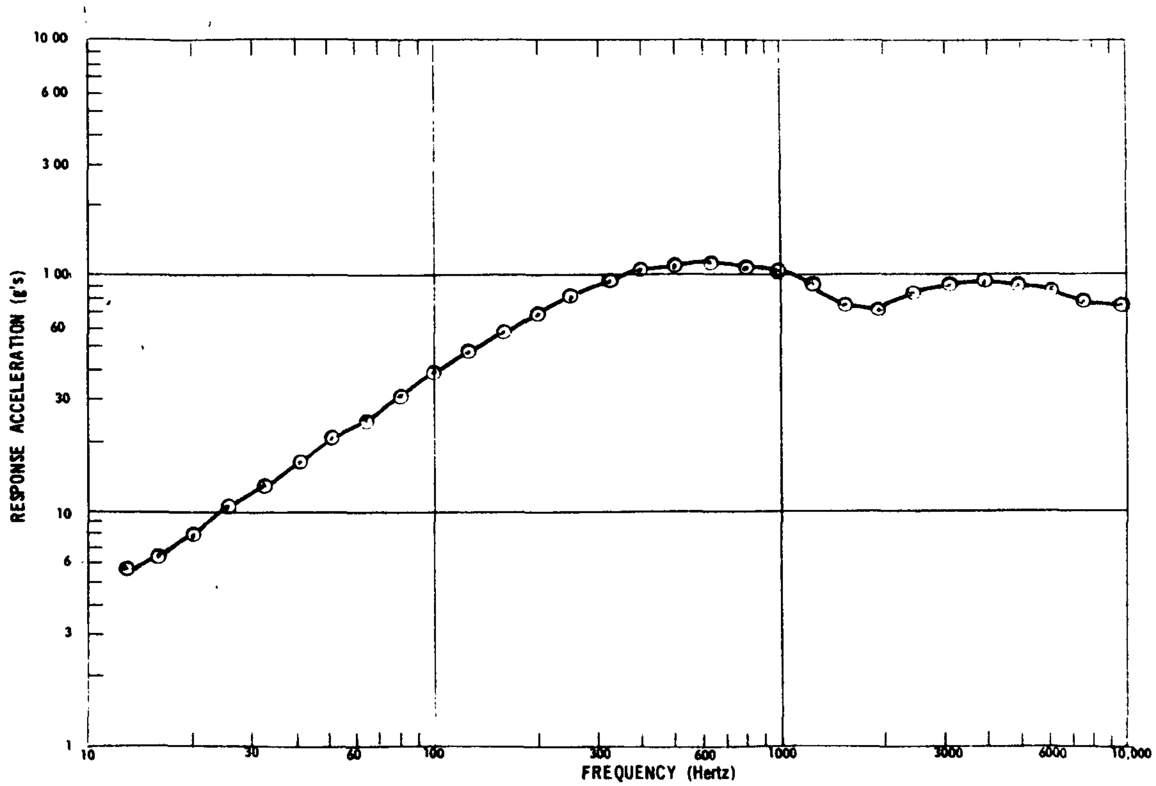


Figure D-8. Polyurethane, 3/4" Thick, Nose Angle Impact, 5" Drop Height

PENDULUM TEST SHOCK SPECTRA

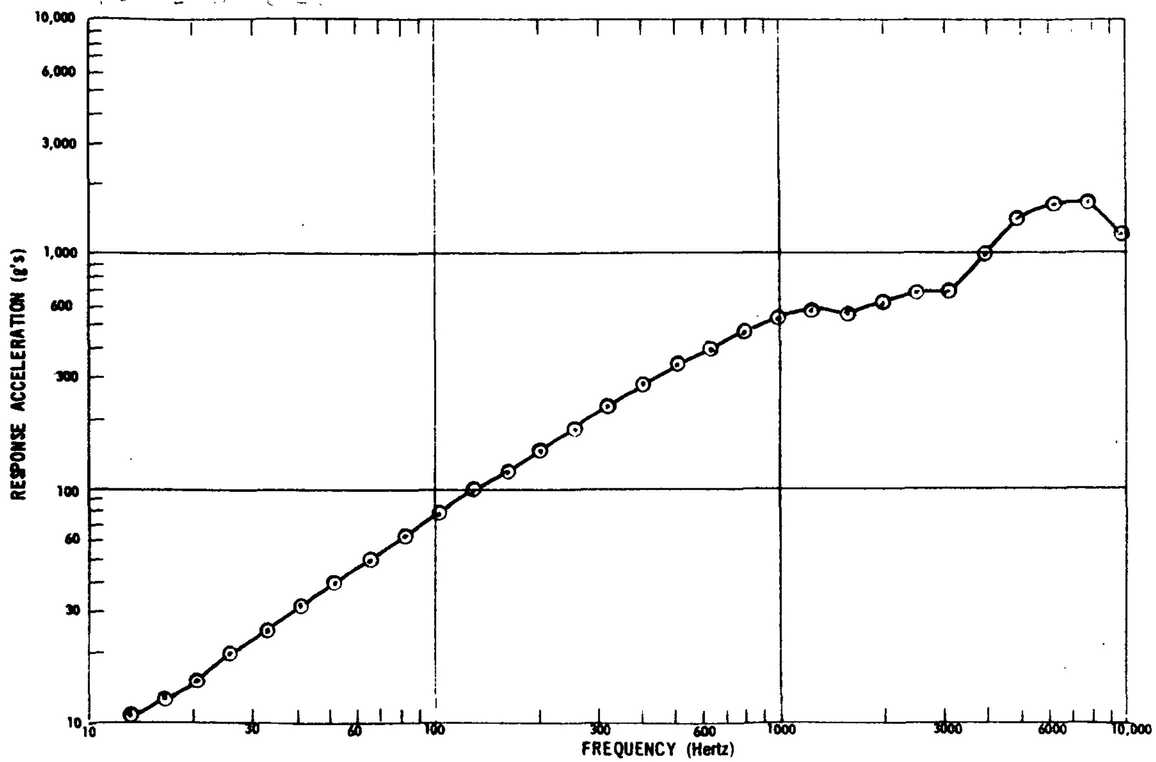


Figure D-9. Polyurethane, 3/4" Thick, Nose Flat Impact, 10" Drop Height

PENDULUM TEST SHOCK SPECTRA

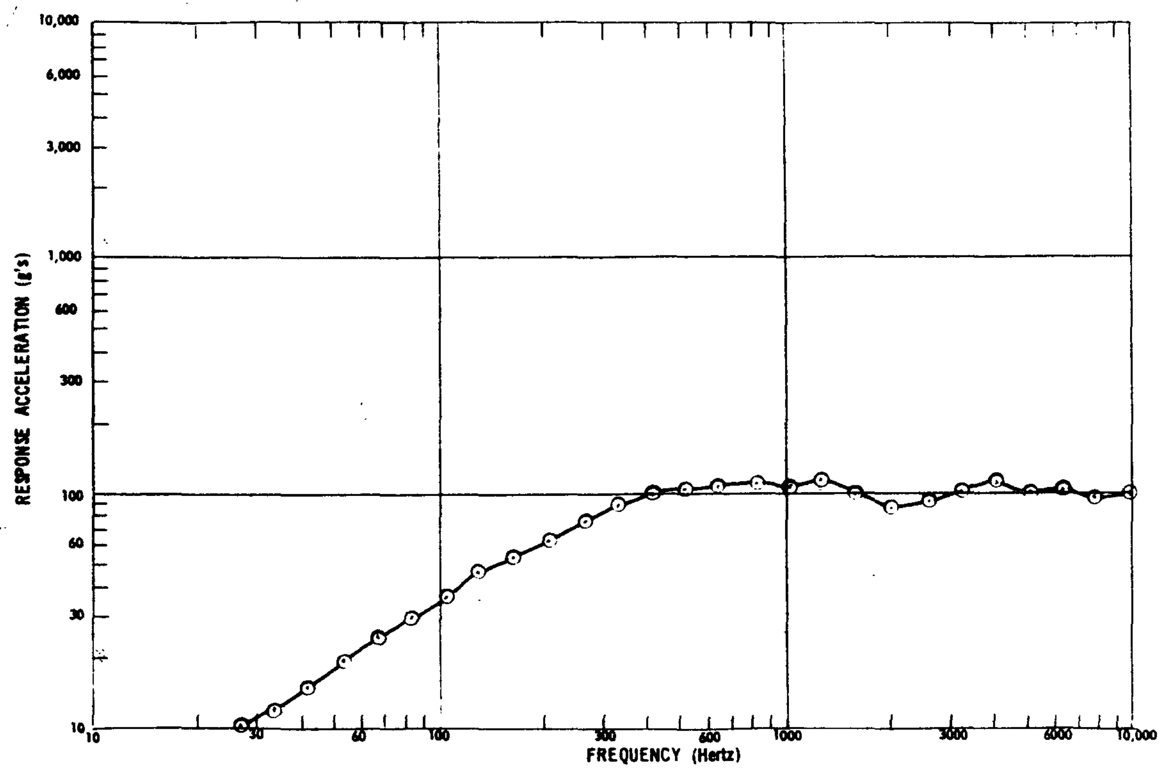


Figure D-10. Polyurethane, 1/4" Thick, Nose Flat Impact, 5" Drop Height

PENDULUM TEST SHOCK SPECTRA

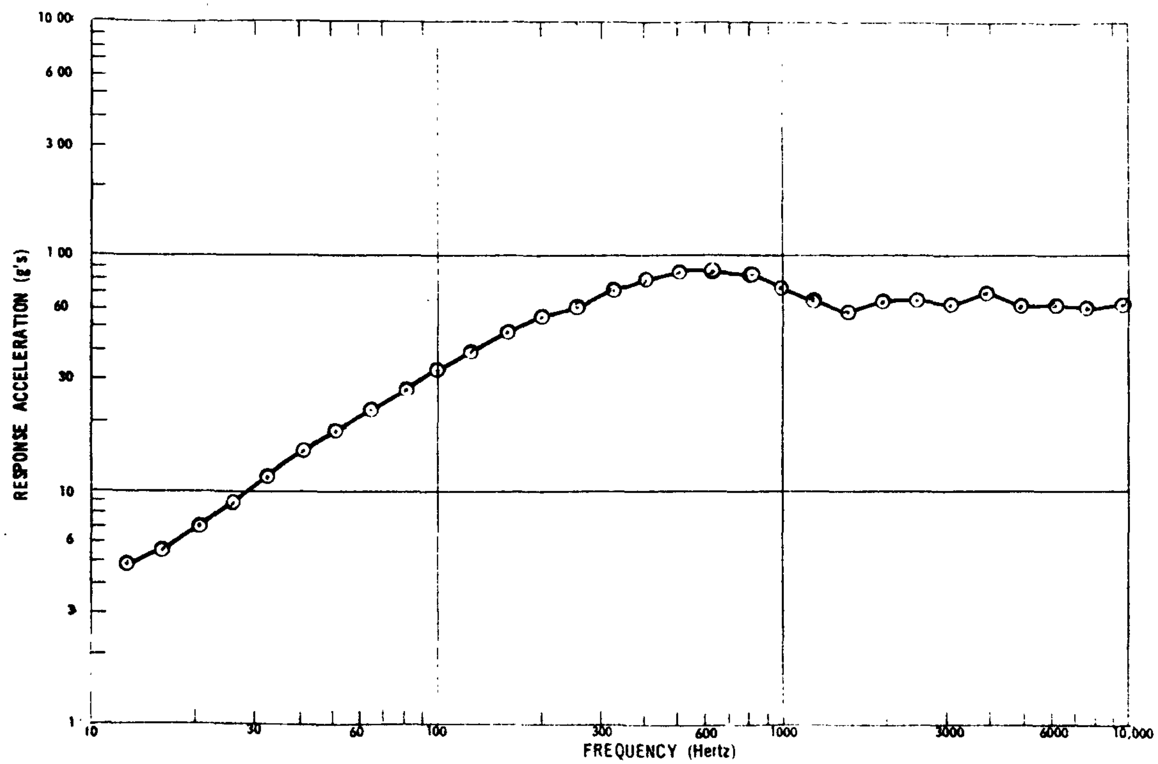


Figure D-11. Polyurethane, 1/4" Thick, Nose Angle Impact, 5" Drop Height

PENDULUM TEST SHOCK SPECTRA

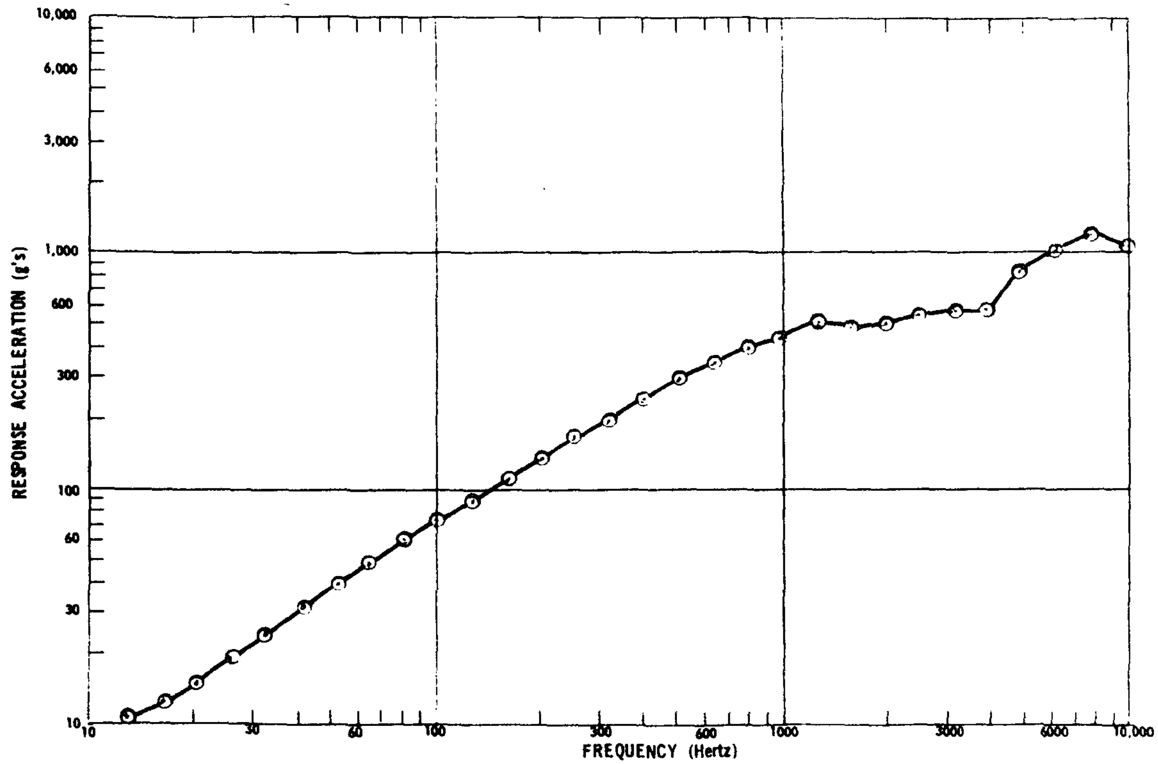


Figure D-12. Polyurethane, 1/4" Thick, Nose Flat Impact, 10" Drop Height

PENDULUM TEST SHOCK SPECTRA

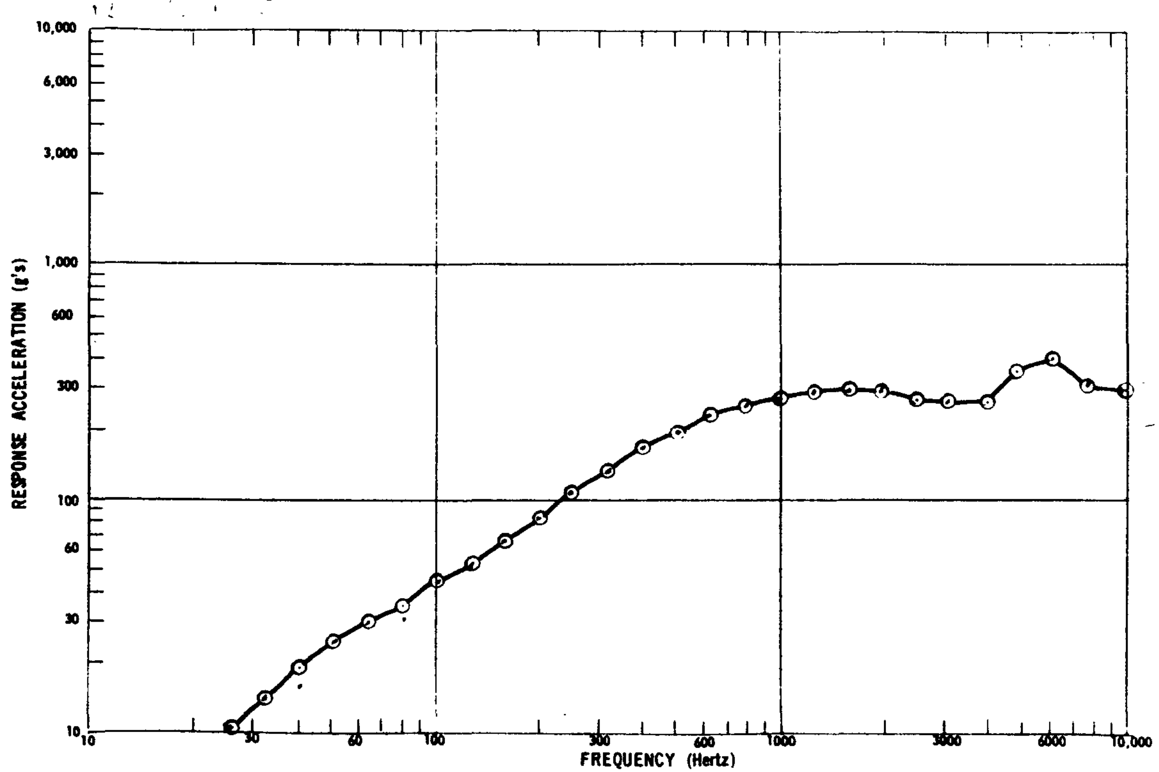


Figure D-13. Polyethylene, 3/4" Thick, Nose Flat Impact, 5" Drop Height

PENDULUM TEST SHOCK SPECTRA

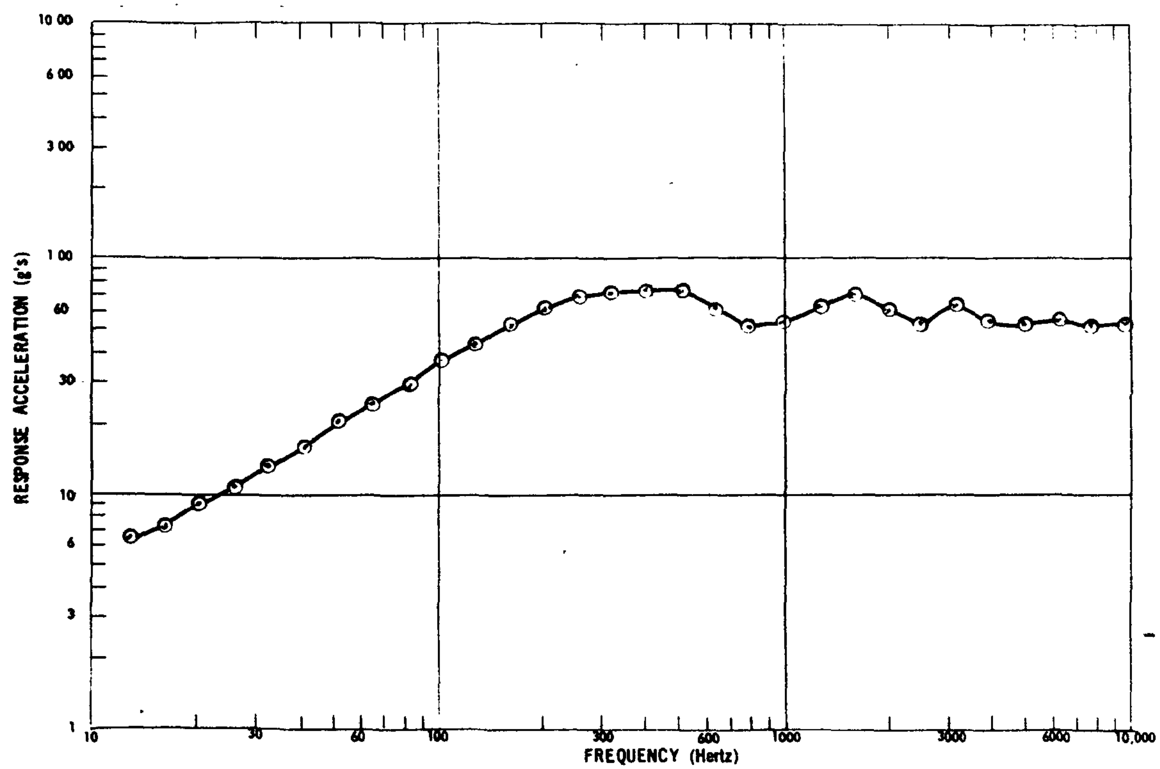


Figure D-14. Polyethylene, 3/4" Thick, Nose Angle Impact, 5" Drop Height

PENDULUM TEST SHOCK SPECTRA

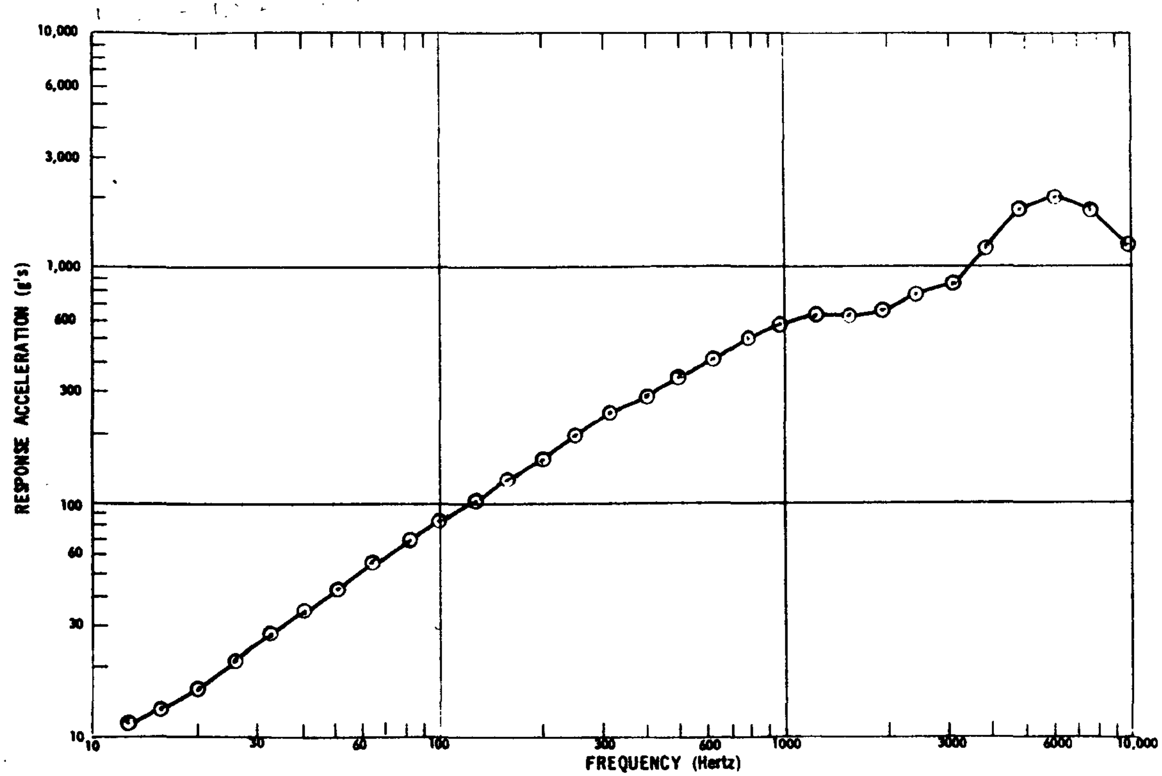


Figure D-15. Polyethylene, 3/4" Thick, Nose Flat Impact, 10" Drop Height

PENDULUM TEST SHOCK SPECTRA

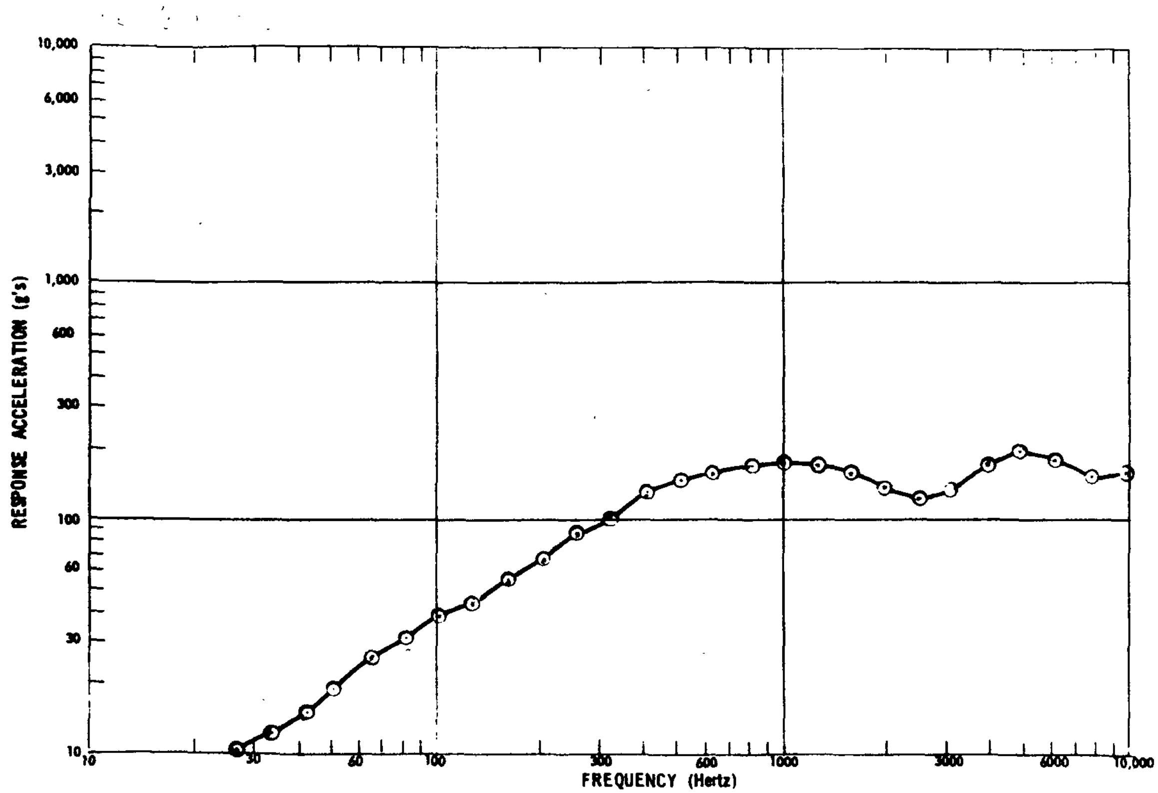


Figure D-16. Polyethylene, 1/4" Thick, Nose Flat Impact, 5" Drop Height

PENDULUM TEST SHOCK SPECTRA

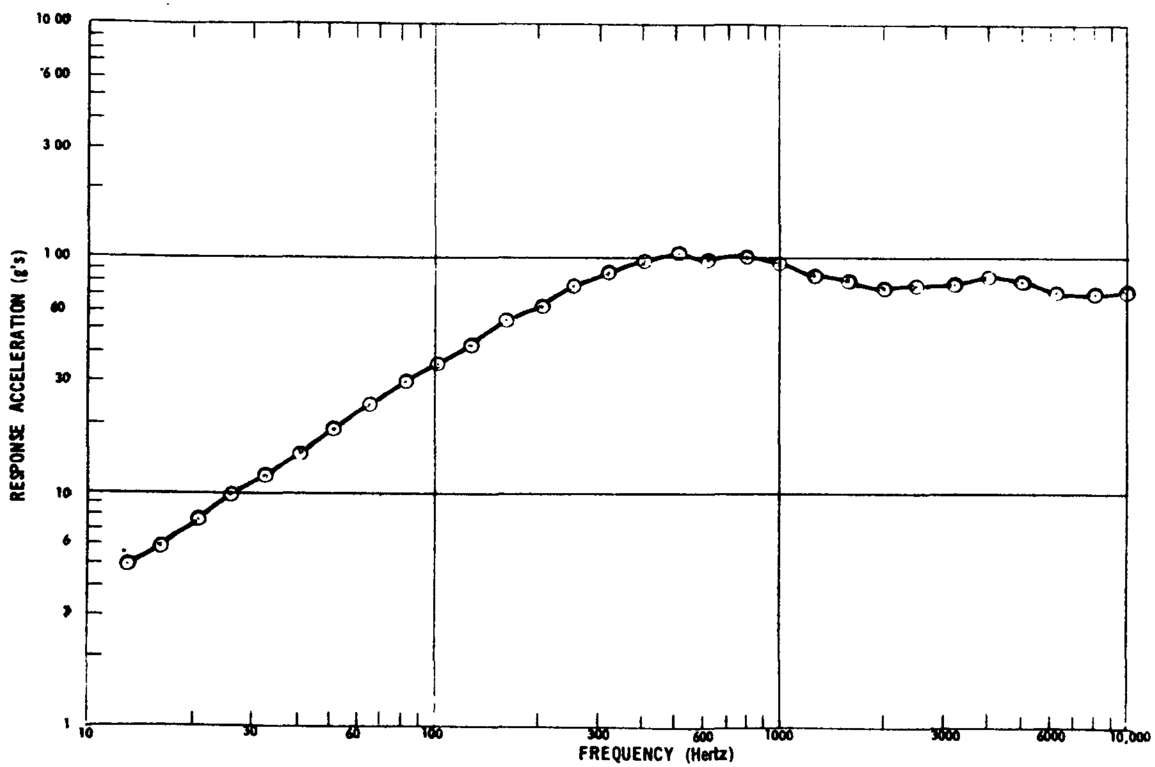


Figure D-17. Polyethylene, 1/4" Thick, Nose Angle Impact, 5" Drop Height

PENDULUM TEST SHOCK SPECTRA

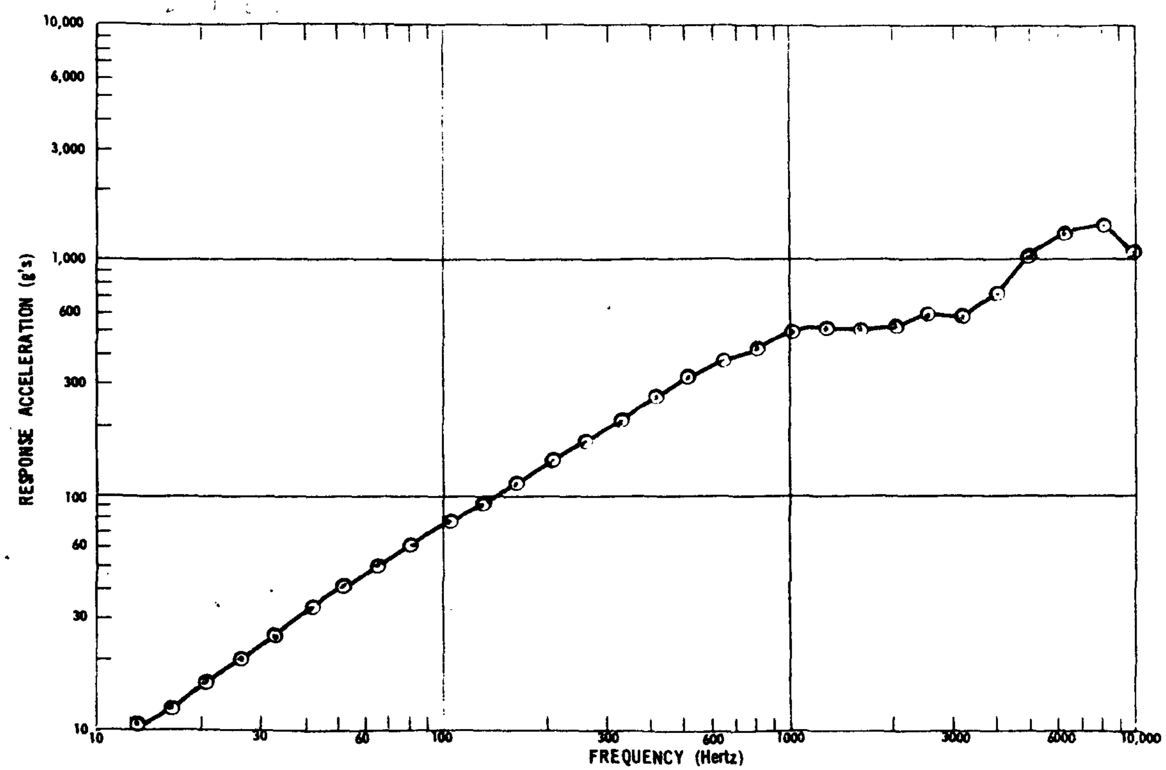


Figure D-18. Polyethylene, 1/4" Thick, Nose Flat Impact, 10" Drop Height

APPENDIX E

PENDULUM TEST TIME HISTORIES

This Appendix contains curves referred to in the Jumble test sub-project section in this report.

PENDULUM TEST TIME HISTORIES

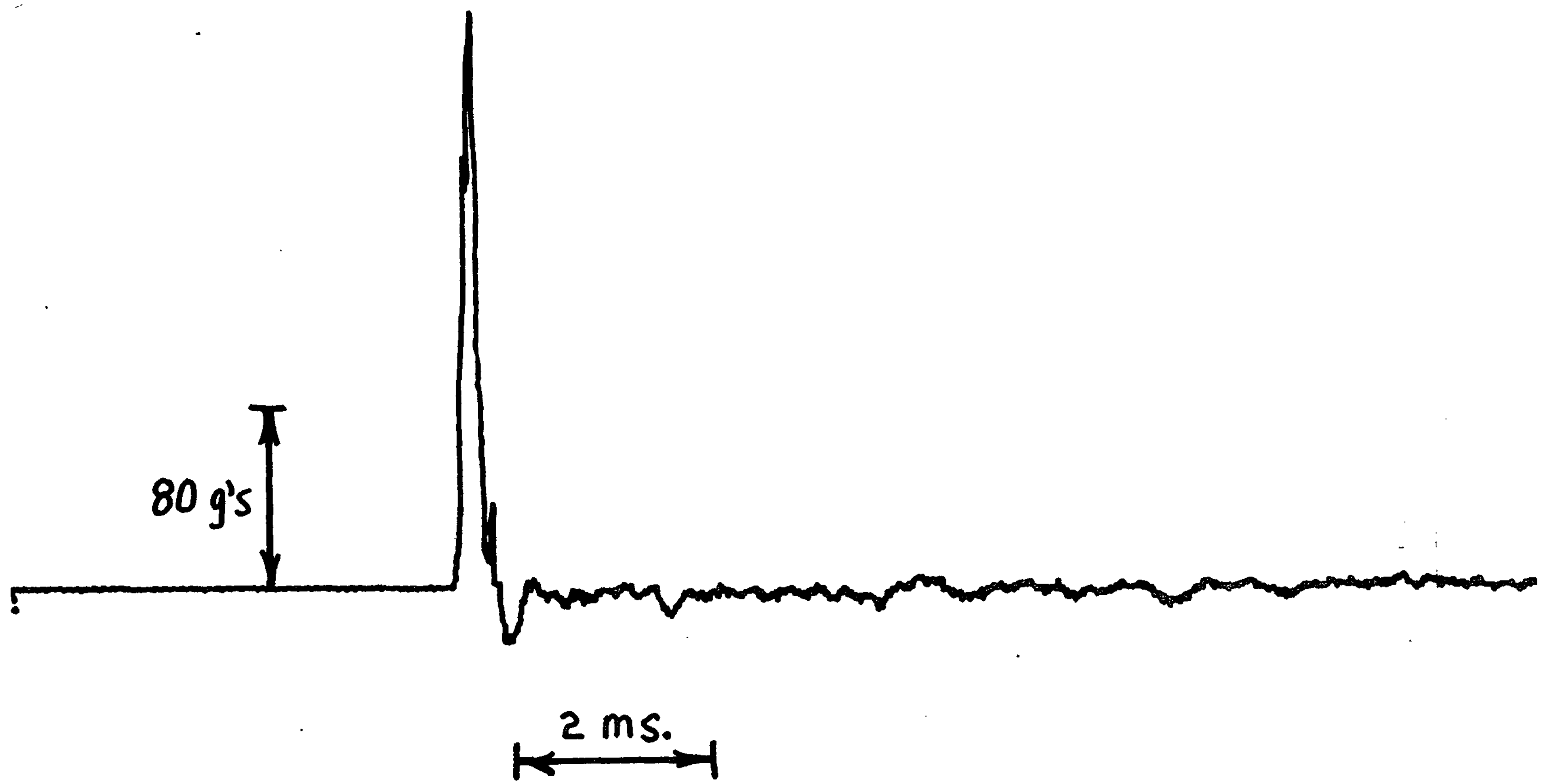


Figure E-1. Wood, 3/4" Thick, Nose Flat Impact, 5" Drop Height

PENDULUM TEST TIME HISTORIES

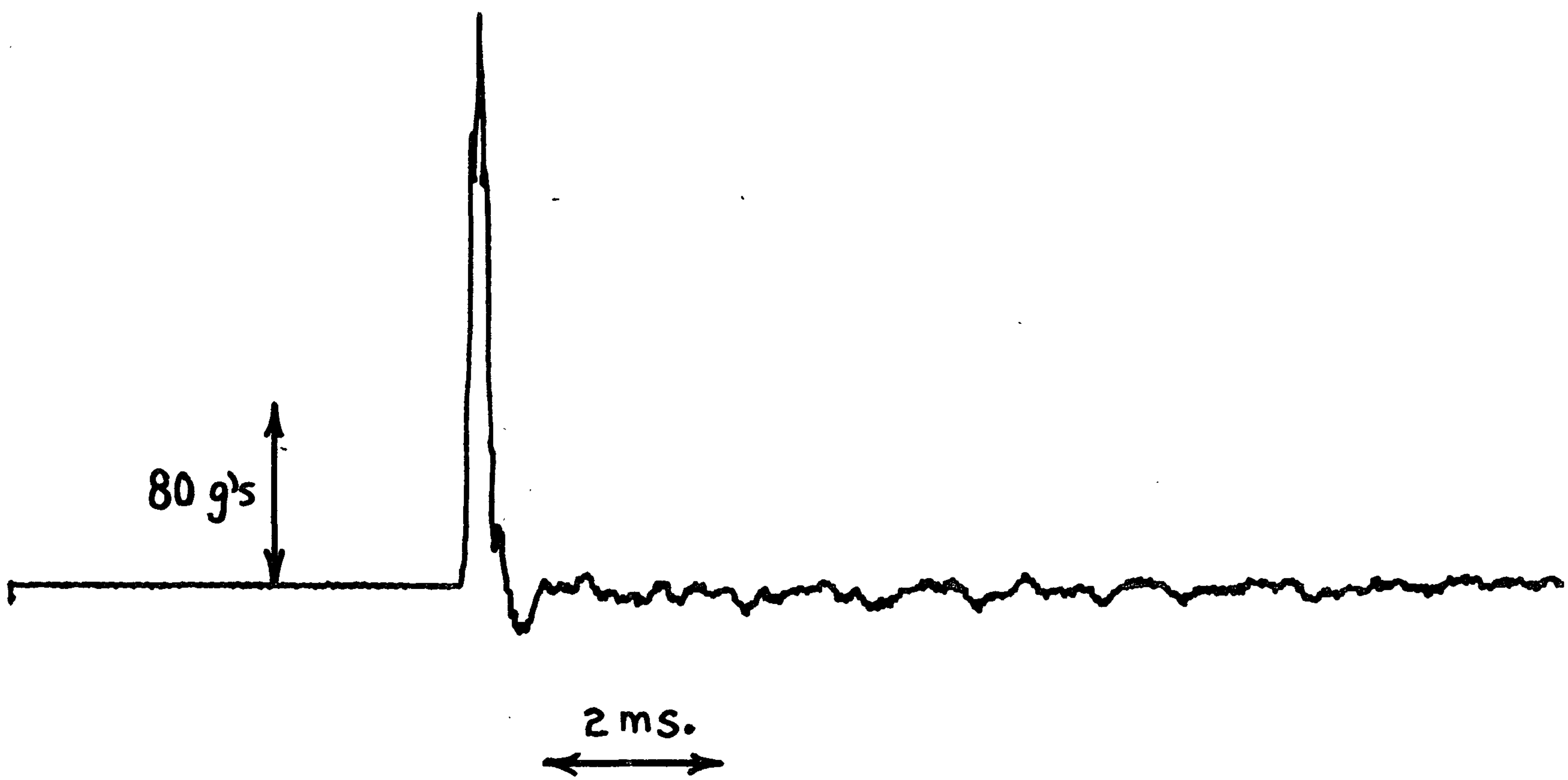


Figure E-2. Polyurethane, 3/4" Thick, Nose flat Impact, 5" Drop Height

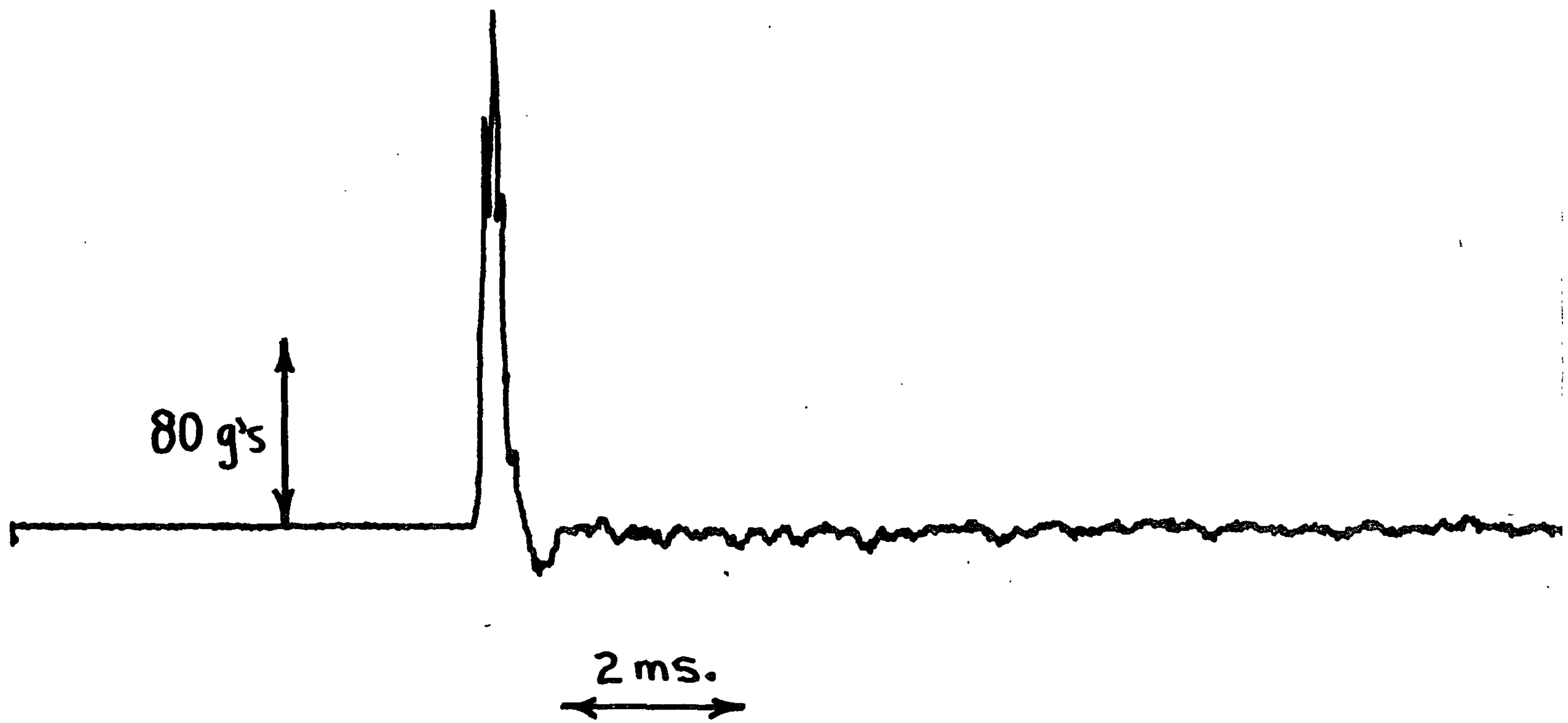


Figure E-3. Polyethylene, 3/4" Thick, Nose Flat Impact, 5" Drop Height

PENDULUM TEST TIME HISTORIES

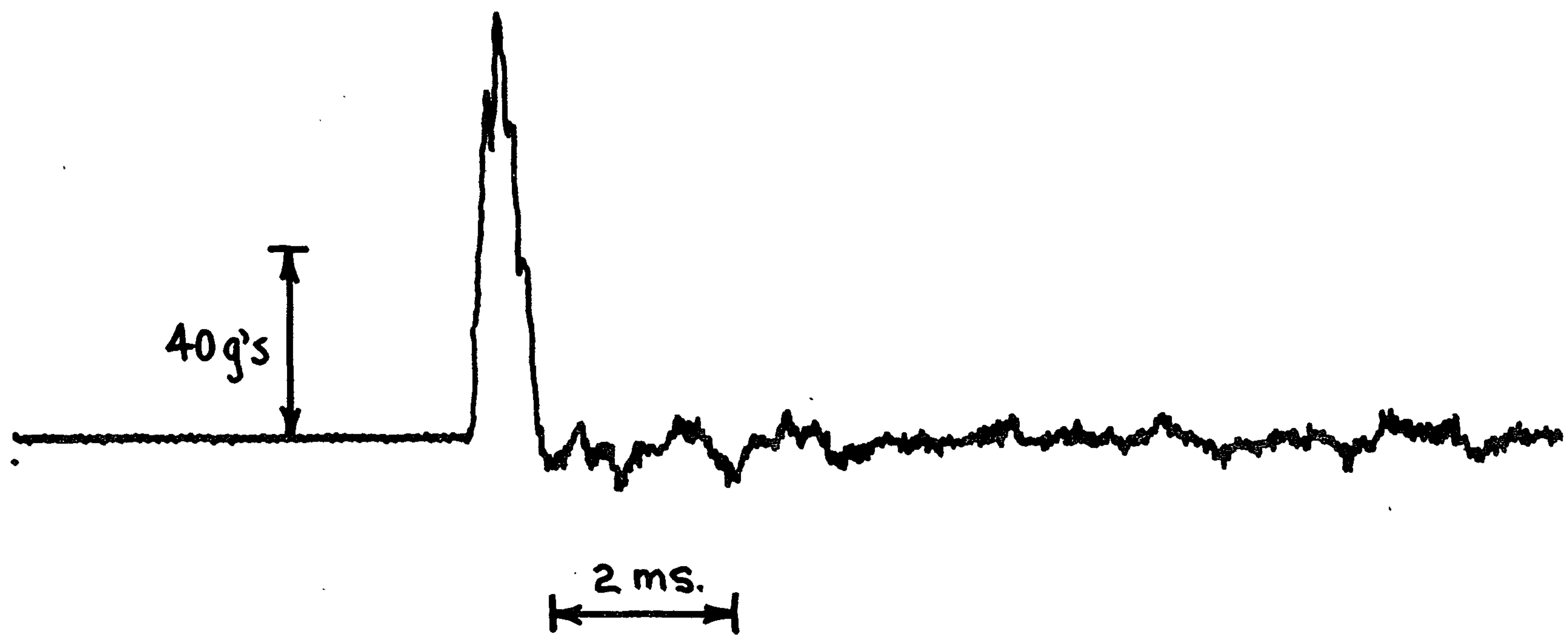


Figure E-4. Wood, 3/4" Thick, Nose Angle Impact, 5" Drop Height

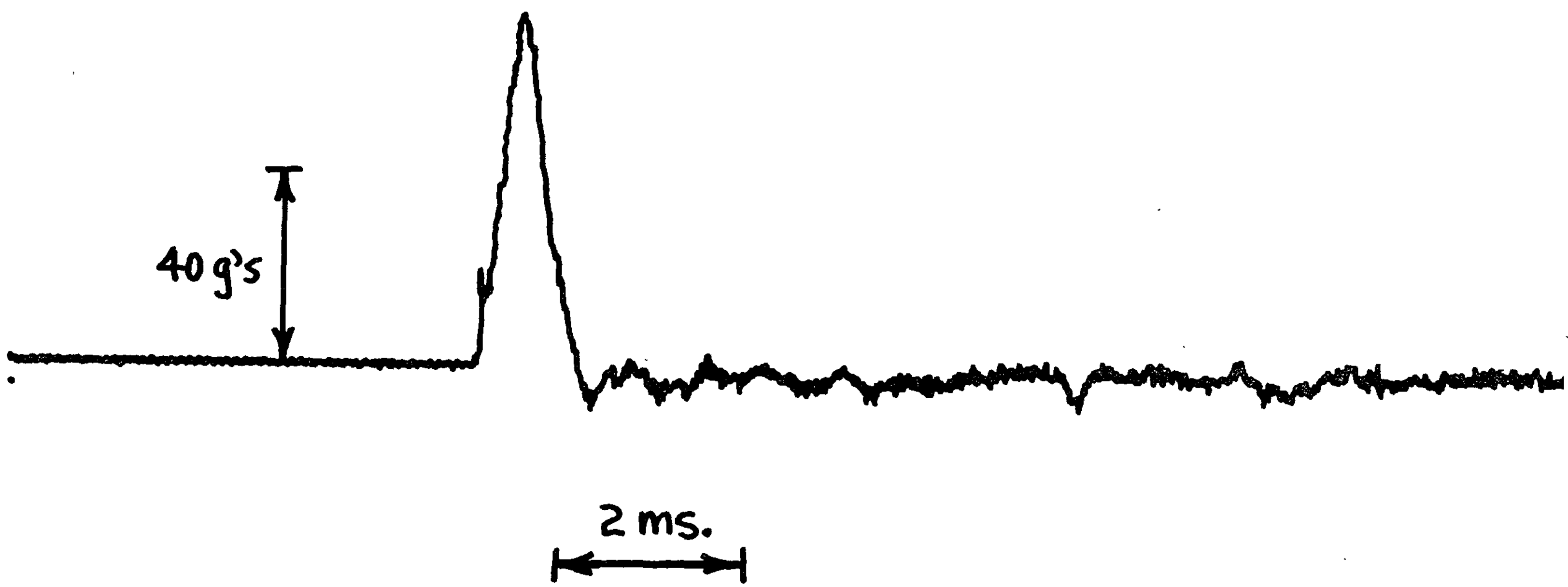


Figure E-5. Polyurethane, 3/4" Thick, Nose Angle Impact, 5" Drop Height

PENDULUM TEST TIME HISTORIES

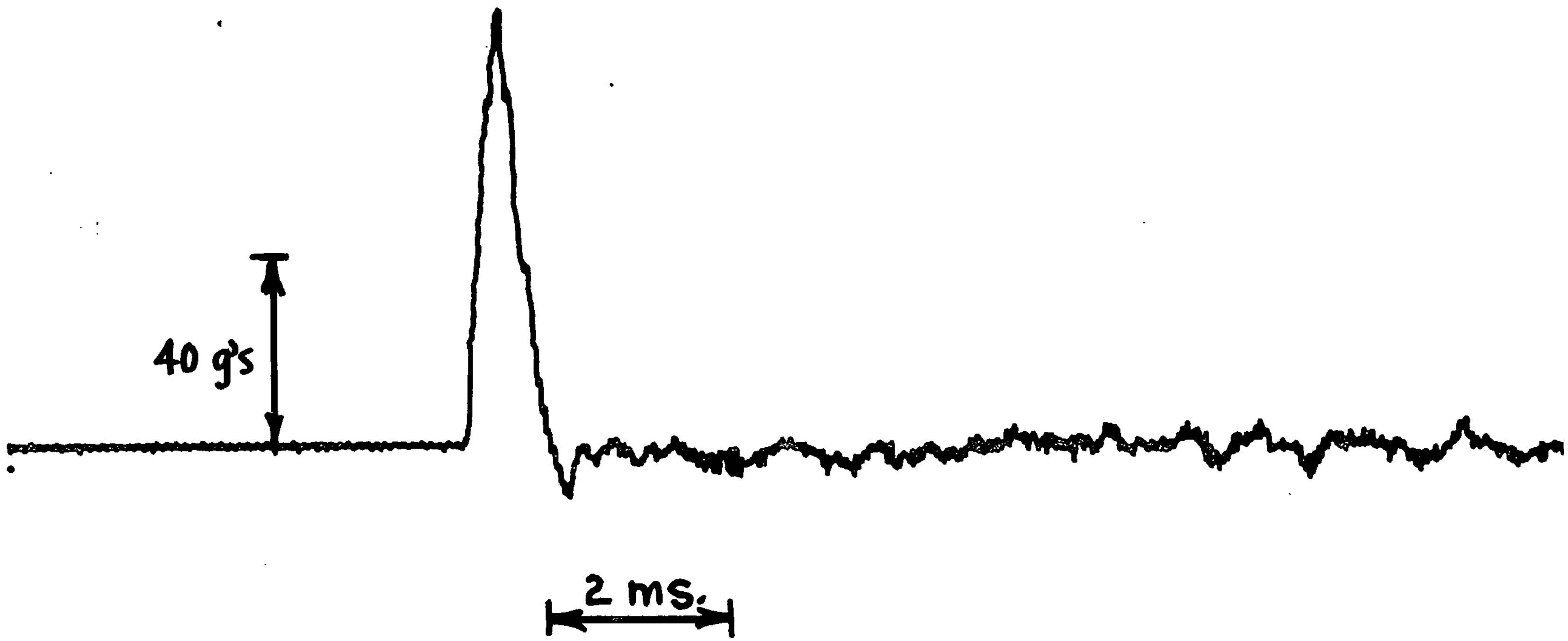


Figure E-6, Polyethylene, 3/4" Thick, Nose Angle Impact, 5" Drop Height

APPENDIX F

Analysis scheme for use with the Drop Tower Monitoring System

This Appendix is extracted from Frankford Arsenal Report No. FA-TM-75027, DETERMINATION OF FUZE IMPACT ANGLE IN DROP TEST FROM ORTHOGONAL PHOTOGRAPHS. Although the analysis scheme presented in this appendix was developed exclusively for use with the Drop Tower Monitoring System, the theory was considered to be of a general nature such that there could be other areas for its application. For this reason, the material was published as a separate report.

INTRODUCTION

The purpose of this task is to determine photographically the angle that a dropped fuze makes with the horizontal plane before impact. This phase of the project is concerned with monitoring the Five and Forty Foot Drop Test in MIL-STD-331. It is part of the AMC project on "Advanced Fuze Test Equipment and Establishment of Refined Measurement Techniques" No.5746310. When a fuze is dropped from various heights the aerodynamic forces on it may cause tumbling with the result that the angle at which it hits the ground is not necessarily the angle at which it was released. Also the release mechanism may cause rotations which will change the intended angle of drop. Measured angles from two simultaneous orthogonal photographs of the fuze close to the ground permit the determination of the actual angle that the fuze makes with the ground.

ANALYSIS

Consider two cameras aligned so that their lines of sight are perpendicular to each other and also perpendicular to the line of fall of the fuze. These three lines will form a three dimensional set of Cartesian axes as shown in Figure 1. The cameras are placed at R and S on the X-axis and Y-axis, respectively. The line of fall of the fuze is assumed to be the Z-axis, that is, the axis of the fuze intersects the Z-axis. The line RO is not necessarily equal to the line SO so that the two in general do not make the same angles, ϕ and ϕ', with the origin and the intersection of the fuze and the Z-axis.

In Figure 1, FP represents the axis of the fuze and Θ is the angle which the fuze makes with the horizontal plane. The projections of FP on the YZ plane as viewed from R, and on the XZ plane as viewed from S are FG and FE, respectively. These projections make angles of α and β with the Y and X axes, respectively. The angles α and β are the angles which the fuze makes on the photographs of the cameras at R and S.

The problem to be solved can be stated as follows: To determine θ from the measured values of α and β taken from the photographs, and from ϕ and ϕ' as determined from the experimental set up.

The orientation of the fuze FP and the cameras R and S in Figure 1 is such that both photographs show positive angles for α and β. As the point P moves in the minus Z direction, one or both of the angles α and β will become negative depending on the position of the two cameras. All of the possible cases for the first octant are shown in Figure 2. There are similar cases in the other octants. However, because of symmetry considerations and the use of a sign convention for the angles, only one case, Figure 1, needs to be analyzed.

In Figure 1, FP represents the axis of the fuze, and the cameras at R and S make angles of ϕ and ϕ', respectively, with the X-and Y-axis and the lines of sight to F. The plane FABC is constructed parallel to the XY

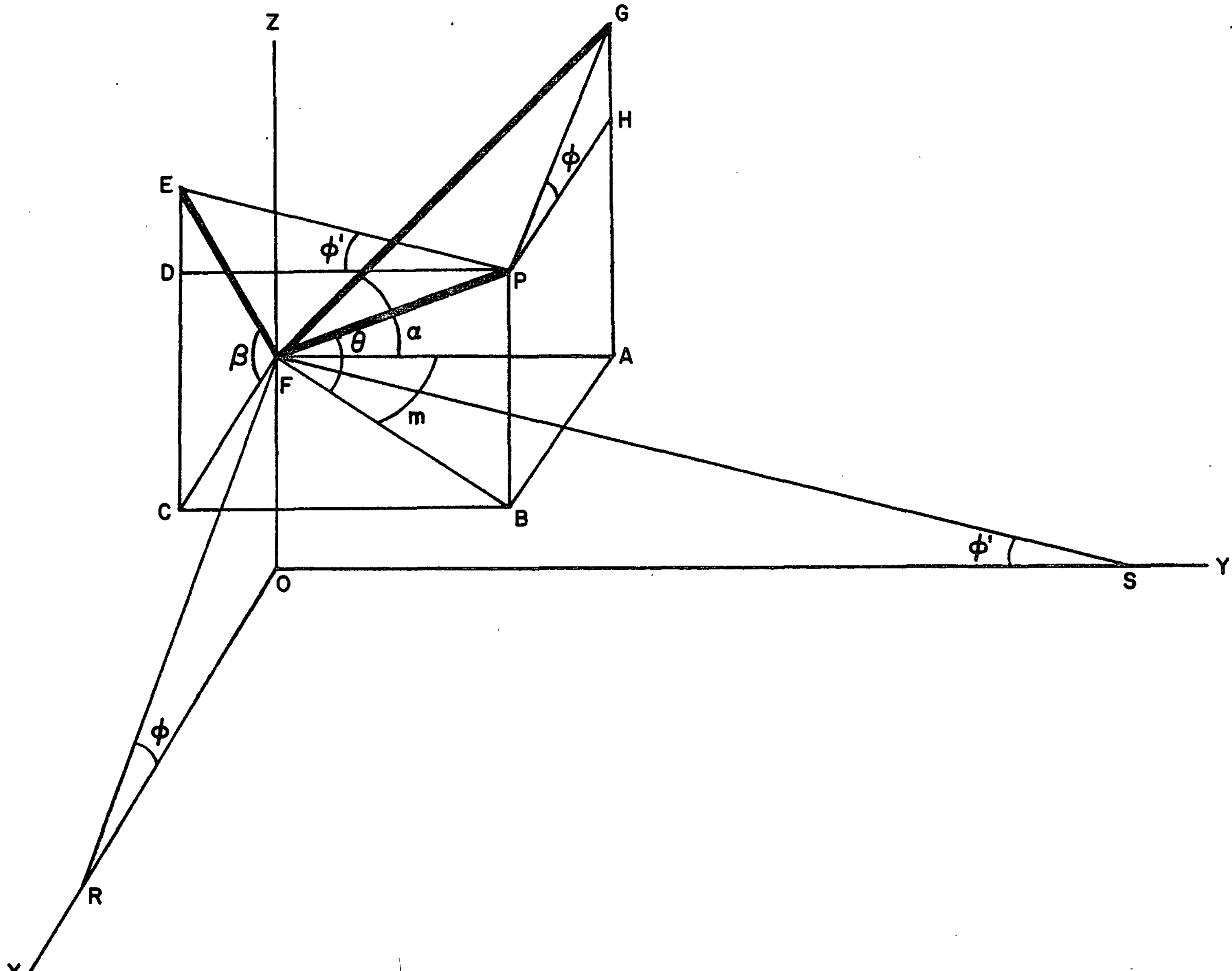
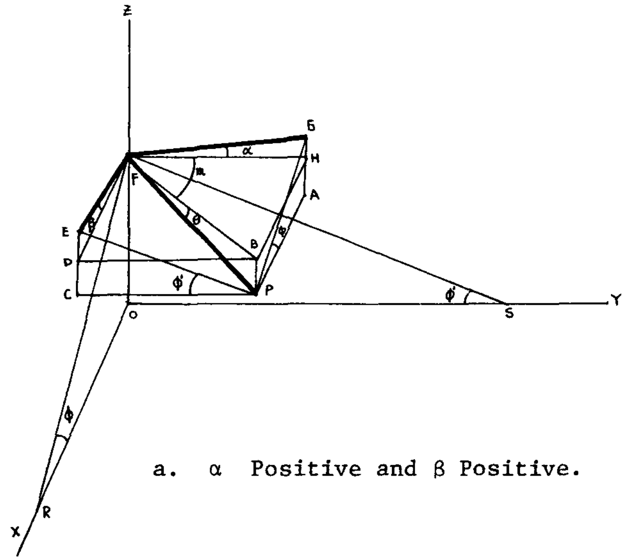
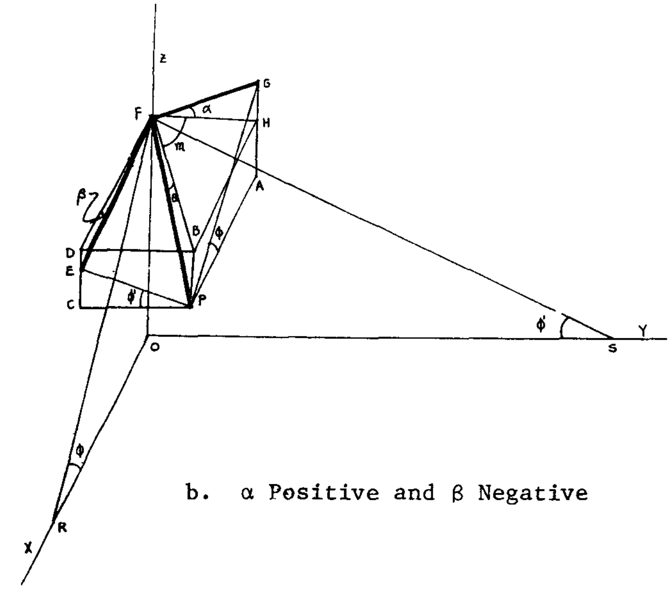


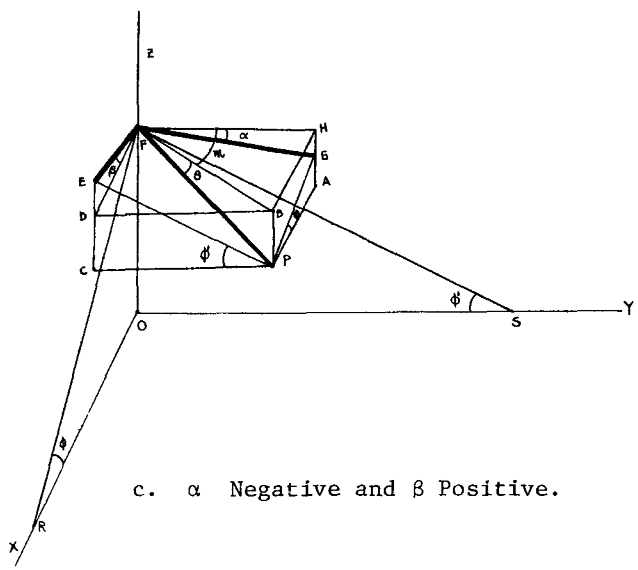
Figure 1. Geometric Arrangement for Fuze Drop Test for both α and β Positive, and θ Positive.



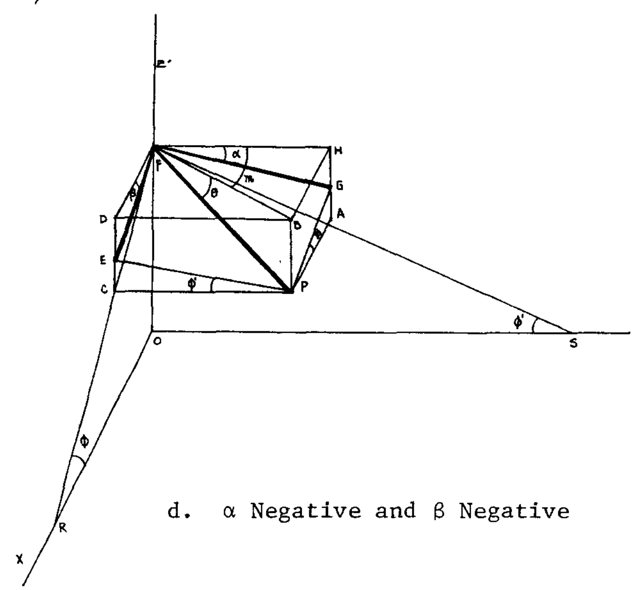
a. α Positive and β Positive.



b. α Positive and β Negative



c. α Negative and β Positive.



d. α Negative and β Negative

Figure 2. Geometric Arrangement for Fuze Drop Test for Various Signs for α and β with θ Negative.

plane with CF parallel to the X-axis, FA and BC parallel to the Y-axis, and PB is parallel to the Z-axis. The angle m is the angle between FB and FA. PD is perpendicular to EC, and PH is perpendicular to GA. The plane PBAHG is constructed parallel to the XZ plane, the plane PBCDE is constructed parallel to the YZ plane. This last statement represents the key to the conctruction since PE is parallel to SF, and hence, angle EPD equals angle FSO, i.e. ϕ'. Similarly the line PG is parallel to RF and hence, angle GPH is equal to angle FRO, i.e. ϕ.

From the above described construction in Figure 1, the following relations can be stated:

$$\left.\begin{aligned}
DE &= FP \cos\theta \cos m \tan\phi' \\
HG &= FP \cos\theta \sin m \tan\phi \\
BP &= FP \sin\theta \\
AH &= BP = CD = FP \sin\theta \\
FA &= CB = FP \cos\theta \cos m \\
AB &= FC = FP \cos\theta \cos m
\end{aligned}\right\} \quad (1)$$

Also from Figure 1 and Equation 1:

$$\left.\begin{aligned}
\tan\alpha &= \frac{AG}{FA} = \frac{AH + HG}{FA} = \tan m \tan\phi + \frac{\tan\theta}{\cos m} \\
\tan\beta &= \frac{CE}{FC} = \frac{CD + DE}{FC} = \cos m \tan\phi' + \frac{\tan\theta}{\sin m}
\end{aligned}\right\} \quad (2)$$

Eliminating m in Equations 2 yields:

$$\left.\tan\theta = \frac{\tan\alpha \tan\beta - \tan\phi \tan\phi'}{\pm\left[(\tan\phi' + \tan\alpha)^2 + (\tan\phi + \tan\beta)^2\right]^{\frac{1}{2}}}\right\} \quad (3)$$

Equation 3 is the desired result for the determination of θ from α, β, ϕ, and ϕ', and this equation can be used for all the possible configurations shown in Figure 2. The sign convention which is used is as follows:

1. ϕ and ϕ' are always positive
2. α is positive if it is measured from the + Y direction to the + Z direct, otherwise it is negative
3. β is positive if it is measured from the + X direction to + Z direction, otherwise it is negative.
4. If α and β are negative and $|\tan\alpha \tan\beta| > \tan\phi \tan\phi'$ then the negative sign of the ambiguity sign ($\pm$) should be used, otherwise the positive sign should be used.

Plots of Equation 3 are shown in Figures 3 to 6. In all of these Figures, θ is plotted vertically, β horizonally, and each curve is for a given α angle. For $\phi = \phi' = 0$, all of the curves go through the origin and the curves are symmetrical with respect to the origin. For this case, because of symmetry, only the first quadrant is shown in Figure 6. For $\phi = \phi' = c_1$, all of the curves go through the point $(-c_1, -c_1)$ as shown in Figure 3. For $\phi = c_1$ and $\phi' = c_1'$, the curves go through the point $(-c_1, -c_1)$ as shown in Figures 4 and 5. For all of these plots there will exist a horizontal limiting straight line at $\theta = -c_1'$ for that value of $\alpha = -\phi'$. At $\beta = -c_1$, this straight line abruptly approaches the point $(-c_1, -c_1)$. This limiting straight line degenerates into the β axis for $\phi' = 0$. There exists another limiting straight line on Figures 3 to 6 which goes through the origin and the point $(-c_1, -c_1)$ for that value of $\alpha = \pm 90^\circ$, and this line is not shown on Figures 3 to 5 because of the computing and plotting limitations. This line has been added to Figure 6.

APPLICATION FOR FUZE DROP TEST

Since, for the experimental work, it is possible to trigger the cameras at any time during the fall of the fuze, it was decided to take the pictures just before the fuze hits the ground. At this point $\phi = \phi' = 0$. The applicable curves for this case are shown in Figure 6. These curves can be used for any values of α and β by measuring the acute angle that the axis of the fuze makes with a horizontal line in both photographs and using these angles for α and β in Figure 6. One then merely finds the intersection of the curve for a particular value of α with the value of β, and reads across to obtain the value of θ. For example, if $\alpha = 40^\circ$ and $\beta = 60^\circ$, then $\theta = 37^\circ$.

For completeness, Table 1 has been added to show the determination of θ for 2° increments in α and β. All numbers in the Table are in degrees. Also, a Flow Chart and Computer Program have been added in an Appendix.

TABLE 1. θ as a Function of α and θ for $\phi = \phi' = 0$
(all numbers are in degrees)

α \ β	0	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42	44
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	0	1	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
4	0	2	3	3	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
6	0	2	3	4	5	5	5	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
8	0	2	4	5	6	6	7	7	7	7	7	8	8	8	8	8	8	8	8	8	8	8	8
10	0	2	4	5	6	7	8	8	9	9	9	9	9	9	10	10	10	10	10	10	10	10	10
12	0	2	4	5	7	8	9	9	10	10	10	11	11	11	11	11	11	11	12	12	12	12	12
14	0	2	4	6	7	8	9	10	11	11	12	12	12	13	13	13	13	13	13	13	13	14	14
16	0	2	4	6	7	9	10	11	11	12	13	13	14	14	14	14	15	15	15	15	15	15	15
18	0	2	4	6	7	9	10	11	12	13	14	14	15	15	15	16	16	16	17	17	17	17	17
20	0	2	4	6	7	9	10	12	13	14	14	15	16	16	17	17	17	18	18	18	18	19	19
22	0	2	4	6	8	9	11	12	13	14	15	16	17	17	18	18	19	19	19	20	20	20	20
24	0	2	4	6	8	9	11	12	14	15	16	17	17	18	19	19	20	20	21	21	21	22	22
26	0	2	4	6	8	9	11	13	14	15	16	17	18	19	20	20	21	22	22	22	23	23	24
28	0	2	4	6	8	10	11	13	14	15	17	18	19	20	21	21	22	23	23	24	24	25	25
30	0	2	4	6	8	10	11	13	14	16	17	18	19	20	21	22	23	24	24	25	25	26	26
32	0	2	4	6	8	10	11	13	15	16	17	19	20	21	22	23	24	25	25	26	27	27	28
34	0	2	4	6	8	10	11	13	15	16	18	19	20	22	23	24	25	25	26	27	28	28	29
36	0	2	4	6	8	10	12	13	15	17	18	19	21	22	23	24	25	26	27	28	29	29	30
38	0	2	4	6	8	10	12	13	15	17	18	20	21	22	24	25	26	27	28	29	30	31	31
40	0	2	4	6	8	10	12	13	15	17	18	20	21	23	24	25	27	28	29	30	31	32	32
42	0	2	4	6	8	10	12	14	15	17	19	20	22	23	25	26	27	28	29	31	32	32	33
44	0	2	4	6	8	10	12	14	15	17	19	20	22	24	25	26	28	29	30	31	32	33	34

α \ β	46	48	50	52	54	56	58	60	62	64	66	68	70	72	74	76	78	80	82	84	86	88	90	α
0			0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8
10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12
14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14
16	15	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16
18	17	17	17	17	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18
20	19	19	19	19	19	19	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20
22	21	21	21	21	21	21	21	21	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22
24	22	22	23	23	23	23	23	23	23	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24
26	24	24	24	25	25	25	25	25	25	25	25	26	26	26	26	26	26	26	26	26	26	26	26	26
28	25	26	26	26	26	27	27	27	27	27	27	27	28	28	28	28	28	28	28	28	28	28	28	28
30	27	27	27	28	28	28	29	29	29	29	29	29	29	30	30	30	30	30	30	30	30	30	30	30
32	28	29	29	29	30	30	30	30	31	31	31	31	31	31	32	32	32	32	32	32	32	32	32	32
34	29	30	30	31	31	32	32	32	32	33	33	33	33	33	34	34	34	34	34	34	34	34	34	34
36	31	31	32	32	33	33	33	34	34	34	35	35	35	35	35	36	36	36	36	36	36	36	36	36
38	32	33	33	34	34	35	35	35	36	36	36	37	37	37	37	37	38	38	38	38	38	38	38	38
40	33	34	34	35	36	36	37	37	37	38	38	38	39	39	39	39	40	40	40	40	40	40	40	40
42	34	35	36	36	37	38	38	39	39	40	40	40	41	41	41	41	41	42	42	42	42	42	42	42
44	35	36	37	38	38	39	40	40	41	41	42	42	42	43	43	43	43	44	44	44	44	44	44	44

TABLE I. θ as a Function of α and θ for $\phi = \phi' = 0$ (cont'd)
(all numbers are in degrees)

α \ β	0	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42	44	46	48	50	52	54	56	58	60	62	64	66	68	70	72	74	76	78	80	82	84	86	88	90	β / α
44	0	2	4	6	8	10	12	14	15	17	19	20	22	24	25	26	28	29	30	31	32	33	34	35	36	37	38	38	39	40	40	41	41	42	42	42	43	43	43	43	44	44	44	44	44	44	44
46	0	2	4	6	8	10	12	14	15	17	19	21	22	24	25	27	28	29	31	32	33	34	35	36	37	38	39	40	40	41	42	42	43	43	44	44	44	45	45	45	46	46	46	46	46	46	46
48	0	2	4	6	8	10	12	14	16	17	19	21	22	24	26	27	29	30	31	33	34	35	36	37	38	39	40	41	42	42	43	44	44	45	45	46	46	47	47	47	47	48	48	48	48	48	48
50	0	2	4	6	8	10	12	14	16	17	19	21	23	24	26	27	29	30	32	33	34	36	37	38	39	40	41	42	43	44	44	45	46	46	47	48	48	48	49	49	49	50	50	50	50	50	50
52	0	2	4	6	8	10	12	14	16	17	19	21	23	25	26	28	29	31	32	34	35	36	38	39	40	41	42	43	44	45	46	47	47	48	49	49	50	50	51	51	51	52	52	52	52	52	52
54	0	2	4	6	8	10	12	14	16	18	19	21	23	25	26	28	30	31	33	34	36	37	38	40	41	42	43	44	45	46	47	48	49	50	50	51	51	52	52	53	53	53	54	54	54	54	54
56	0	2	4	6	8	10	12	14	16	18	19	21	23	25	27	28	30	32	33	35	36	38	39	40	42	43	44	45	46	47	48	49	50	51	52	53	53	54	54	55	55	55	56	56	56	56	56
58	0	2	4	6	8	10	12	14	16	18	20	21	23	25	27	29	30	32	33	35	37	38	40	41	42	44	45	46	47	49	50	51	52	53	53	54	55	55	56	57	57	57	58	58	58	58	58
60	0	2	4	6	8	10	12	14	16	18	20	21	23	25	27	29	30	32	34	35	37	39	40	42	43	44	46	47	48	50	51	52	53	54	55	56	56	57	58	58	59	59	60	60	60	60	60
62	0	2	4	6	8	10	12	14	16	18	20	22	23	25	27	29	31	32	34	36	37	39	41	42	44	45	47	48	49	51	52	53	54	55	56	57	58	59	60	60	61	61	62	62	62	62	62
64	0	2	4	6	8	10	12	14	16	18	20	22	24	25	27	29	31	33	34	36	38	40	41	43	44	46	47	49	50	52	53	54	55	57	58	59	60	60	61	62	63	63	63	64	64	64	64
66	0	2	4	6	8	10	12	14	16	18	20	22	24	25	27	29	31	33	35	36	38	40	42	43	45	46	48	50	51	53	54	55	57	58	59	60	61	62	63	64	64	65	65	66	66	66	66
68	0	2	4	6	8	10	12	14	16	18	20	22	24	26	27	29	31	33	35	37	38	40	42	44	45	47	49	50	52	53	55	56	58	59	60	61	63	64	65	65	66	67	67	68	68	68	68
70	0	2	4	6	8	10	12	14	16	18	20	22	24	26	28	29	31	33	35	37	39	41	42	44	46	48	49	51	53	54	56	57	59	60	61	63	64	65	66	67	68	69	69	70	70	70	70
72	0	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	31	33	35	37	39	41	43	44	46	48	50	51	53	55	56	58	60	61	63	64	65	67	68	69	70	71	71	72	72	72	72
74	0	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	35	37	39	41	43	45	47	48	50	52	54	55	57	59	60	62	64	65	67	68	69	70	71	72	73	74	74	74	74
76	0	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	37	39	41	43	45	47	49	51	52	54	56	58	60	61	63	65	66	68	69	71	72	73	74	75	75	76	76	76
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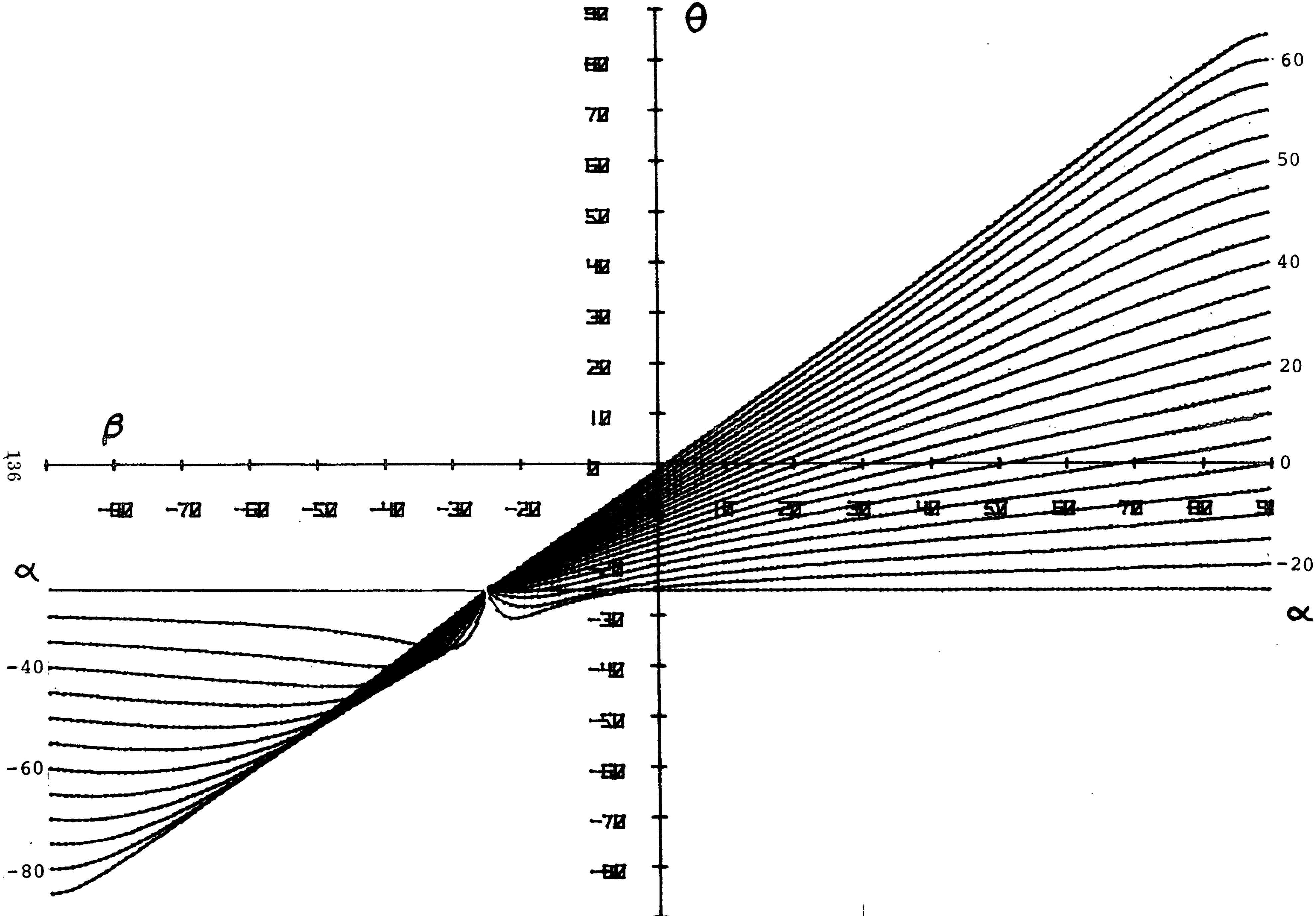


Figure 3. θ as a Function of α and β for $\phi = \phi' = 25^{o}$.

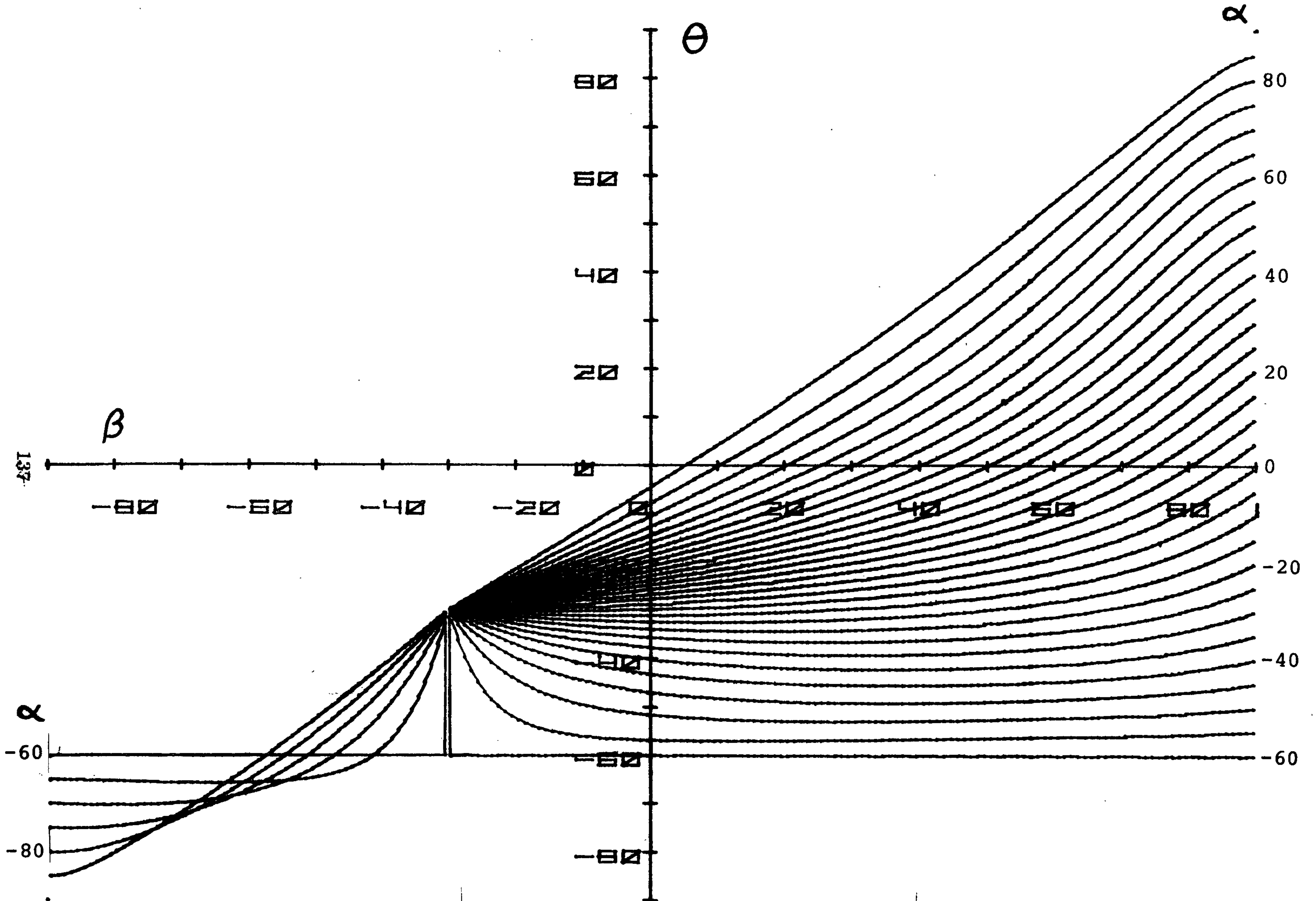


Figure 4. θ as a Function of α and β for $\phi = 30^{o}$ and $\phi' = 60^{o}$.

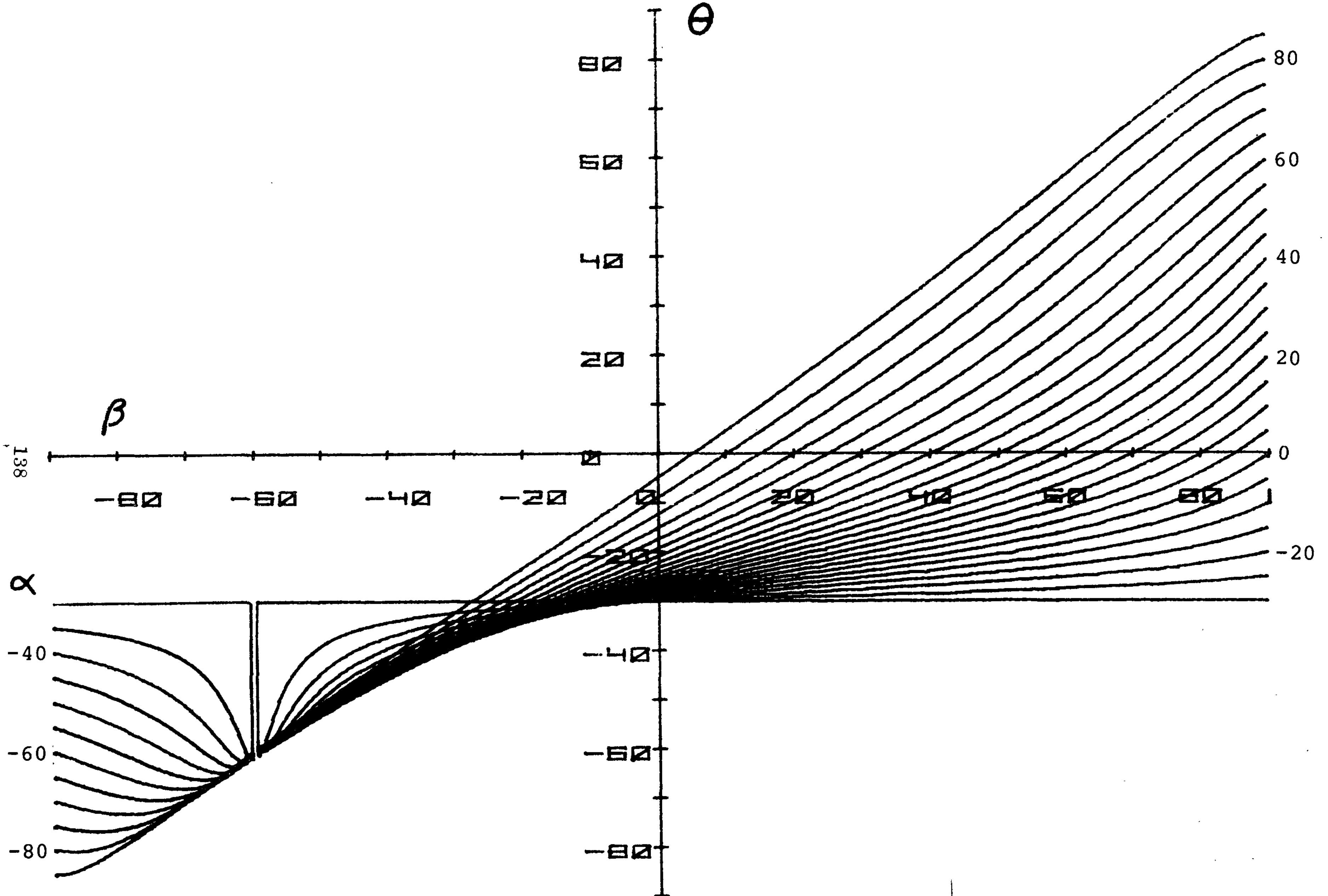


Figure 5. θ as a Function of α and β for $\phi = 60^o$ and $\phi' = 30^o$.

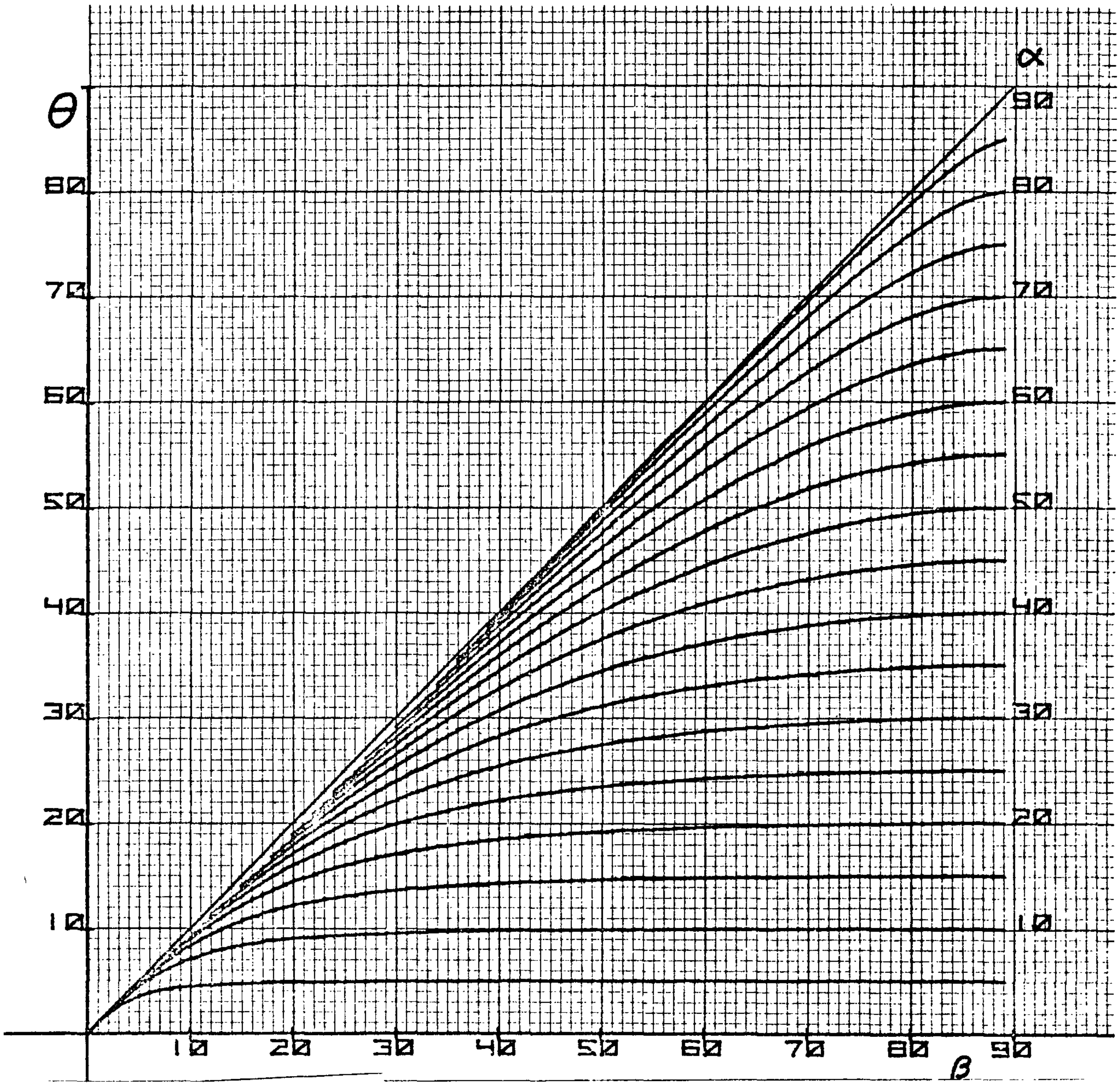


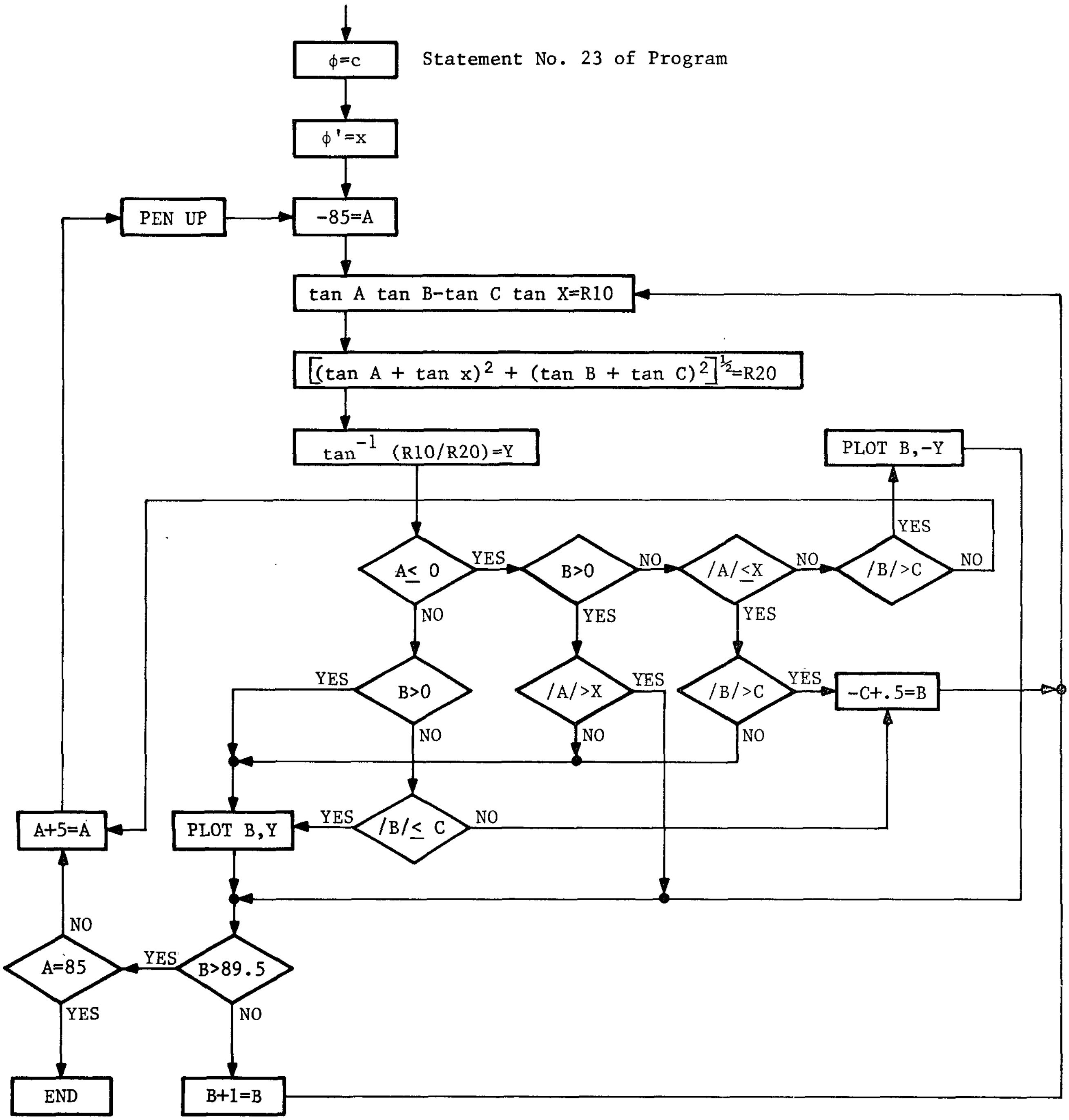
Figure 6. θ as a Function of α and β for $\phi = \phi' = 0$.

APPENDIX

COMPUTER PROGRAM

```
0:
SCL -90,90,-90,9
0⊢
1:
AXE 0,0,10,10⊢
2:
-83→R70⊢
3:
-10→R80⊢
4:
-80→R90⊢
5:
FXD 0⊢
6:
"G";LTR R70,R80,
221⊢
7:
IF R90=-10;GTO "
J"⊢
8:
PLT R90⊢
9:
IF R70>80;GTO "H
"⊢
10:
"J";R70+20→R70⊢
11:
R90+20→R90⊢
12:
GTO "G"⊢
13:
"H";-11→R40⊢
14:
-82→R50⊢
15:
-80→R60⊢
16:
"I";LTR R40,R50,
221⊢
17:
IF R60=-10;GTO "
K"⊢
18:
PLT R60⊢
19:
IF R50>80;GTO "T
"⊢
20:
"K";R50+20→R50⊢
21:
R60+20→R60⊢
22:
GTO "I"⊢
23:
"T";ENT "PHI=",C
⊢
24:
ENT "PHI PRIME="
,X⊢
25:
-85→A⊢
26:
GTO "/"⊢
27:
"*";PEN ⊢
28:
"/";-89.5→B⊢
29:
GTO "-"⊢
30:
"P";-C+.5→B⊢
31:
"-";TAN ATAN B-
TAN CTAN X→R10⊢
32:
√((TAN A+TAN X)↑
2+(TAN B+TAN C)↑
2)→R20⊢
33:
ATN (R10/R20)→Y⊢
34:
IF A≤0;GTO "10"⊢
35:
IF B>0;GTO "A"⊢
36:
IF ABS B≤C;GTO "
A"⊢
37:
GTO "P"⊢
38:
"10";IF B>0;GTO
"20"⊢
39:
IF ABS A≤X;GTO "
30"⊢
40:
IF ABS B>C;GTO "
R"⊢
41:
GTO "S"⊢
42:
"20";IF ABS A>X;
GTO "R"⊢
43:
GTO "A"⊢
44:
"30";IF ABS B>C;
GTO "P"⊢
45:
GTO "A"⊢
46:
"A";PLT B,Y⊢
47:
GTO "R"⊢
48:
"B";PLT B,-Y⊢
49:
"R";IF B>89.5;
GTO "90"⊢
50:
B+1→B⊢
51:
GTO "-"⊢
52:
"90";IF A=85;
GTO "+"⊢
53:
"S";A+5→A⊢
54:
GTO "*"⊢
55:
"+";PRT "THE END
"⊢
56:
END ⊢
R303
```

FLOW CHART OF COMPUTER PROGRAM



APPENDIX G

Delay time calculation for use with the Drop Tower Monitoring System

For the constant acceleration of gravity, the free falling velocity of a test item in the drop tower can be found from:

$$V = V_0 + at \qquad (1)$$

where v = velocity an any time t (in/sec)

v_o = initial velocity at t = 0 (in/sec)

a = acceleration due to gravity (in/sec)

t = time (sec)

in addition, the test item's location above the impact surface can be determined at any time after release from:

$$S = S_o + V_o t + 1/2at^2 \qquad (2)$$

where s = height above impact surface (in)

s_o = initial height at t = 0 (in)

In the drop tower the initial velocity is zero. Also, the acceleration due to gravity is -386 in/sec^2. Therefore equations (1) & (2) become

$$V = -386t \qquad (1a)$$

$$S = S_o - 193t^2 \qquad (2a)$$

The time delay of interest is that time it takes the test item to fall between the ballistic screen and the camera lens. One method for estimating the time delay is to calculate the time it takes a free falling body to reach the camera boxes (t_1) and subtract from this the time it takes the free falling body to reach the ballistic screen boxes (t_2). That is, for a 40 foot drop with the camera boxes 10 inches above the impact surface and the ballistic screen boxes 44 inches above the impact surface:

$$t_1 = \sqrt{\frac{480-10}{193}} = 1.56 \text{ sec.} \qquad (3)$$

$$t_2 = \sqrt{\frac{480-44}{193}} = 1.50 \text{ sec.}$$

The time delay is then given by

$$\Delta t = (t_1 - t_2) \times 1000 = 60 \text{ ms.} \tag{4}$$

In general, the time delay can be estimated by

$$\Delta t = \left[\sqrt{S_o - S_1} - \sqrt{S_0 - S_2}\right] \times 71.9 \tag{5}$$

where S_o = release height (in.)

S_1 = height of the camera lens above the impact surface (in.)

S_2 = height of the ballistic screen above the impact surface (in.)

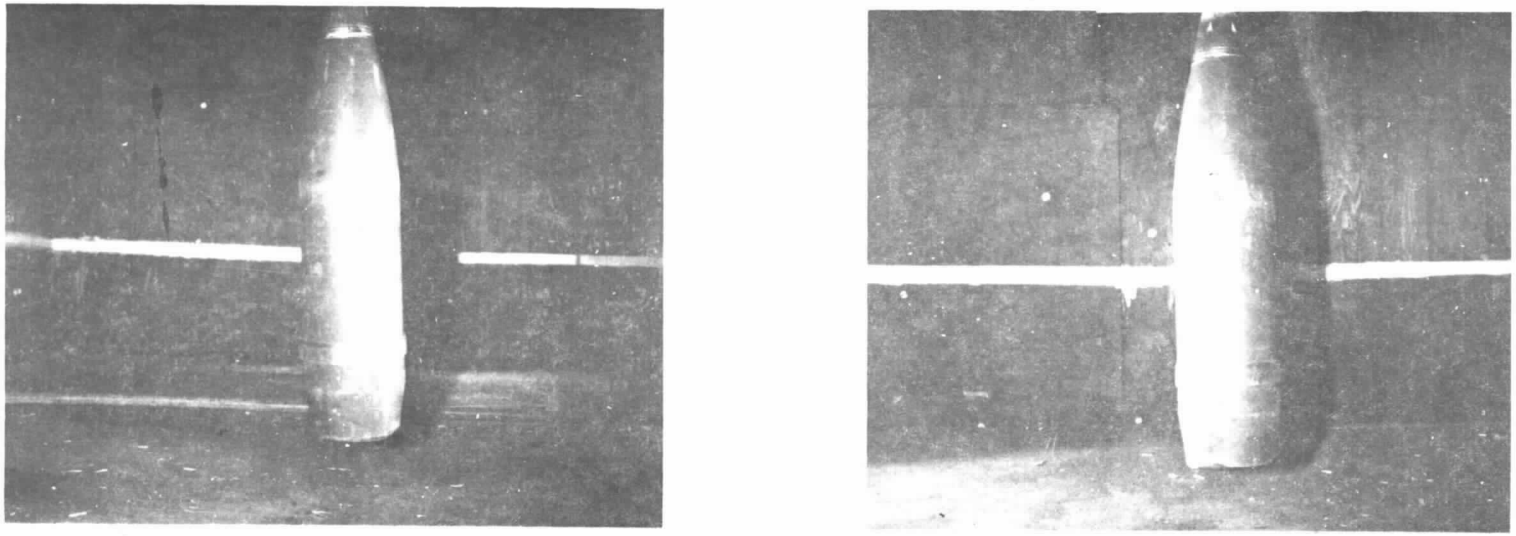
Δt = time delay (ms.)

Therefore, for a five foot drop the time delay is found to be

$$\Delta t = \left[\sqrt{60 - 10} - \sqrt{60 - 44}\right] \times 71.9 = 220 \text{ ms.}$$

APPENDIX H

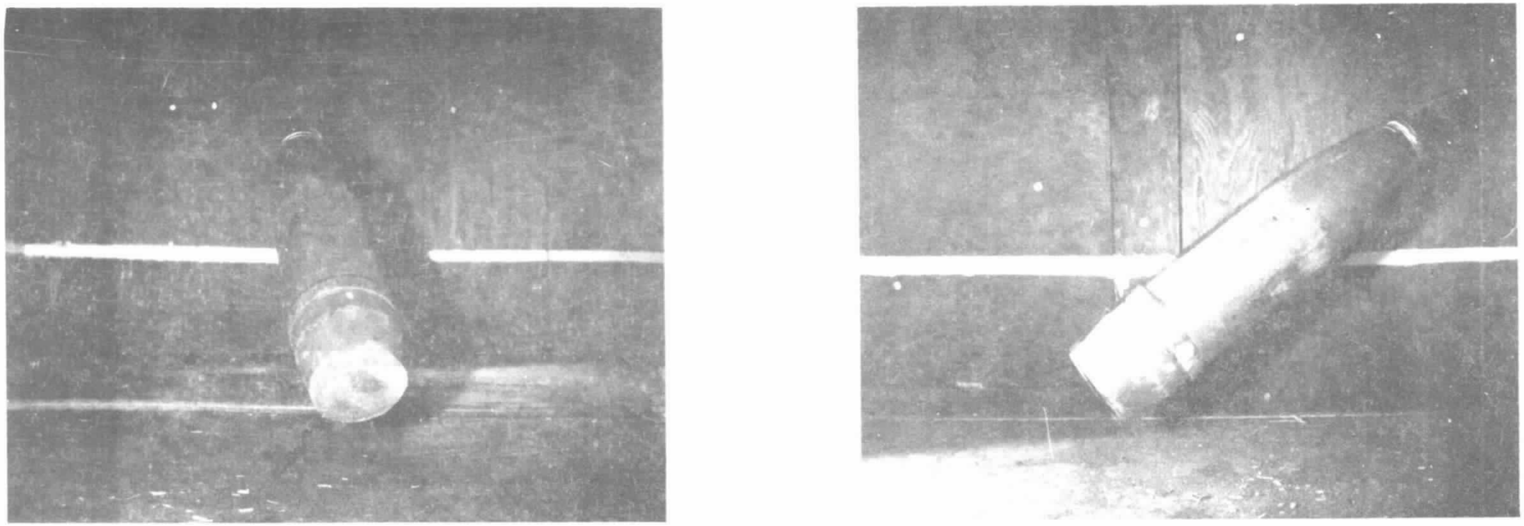
Photographs of a Five Foot Drop test using the drop tower monitoring system.



$\alpha = 86^{o}$ $\theta = 86^{o}$ $\beta = 88^{o}$

Note: Monitoring system programmed for 238 ms time delay; α and β are acute angles measured from horizontal reference line, θ is true angle of impact.

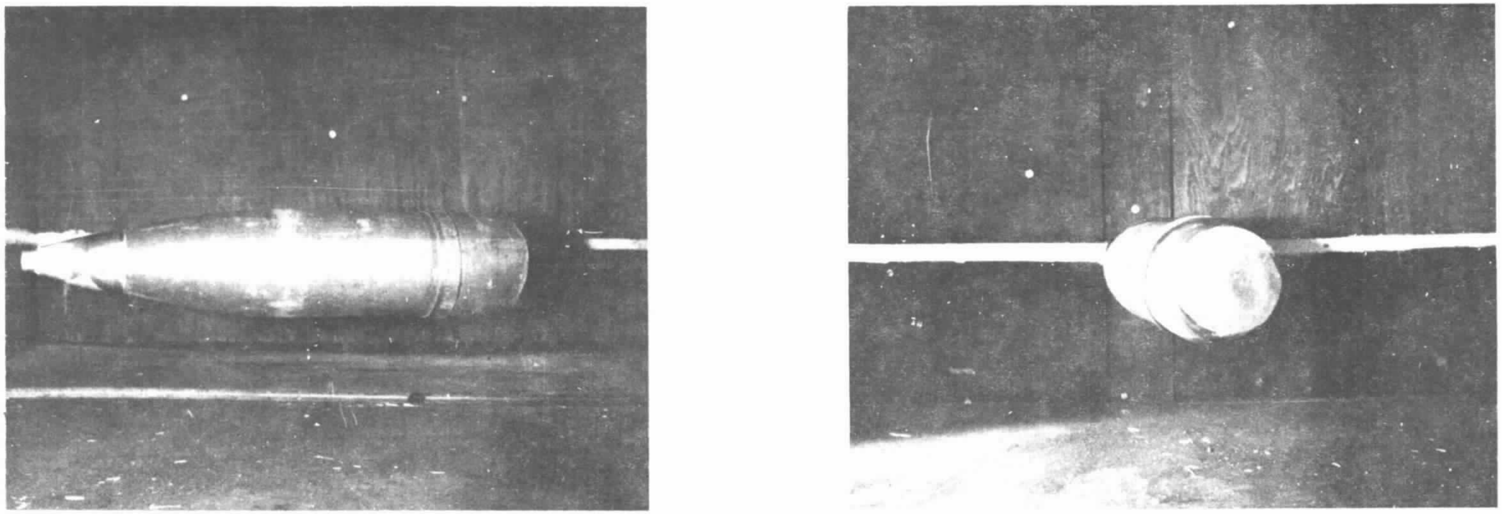
Figure H-1. Photographs of a Five Foot Drop Test, Nose-Up Drop



$\alpha = 75^{o}$ $\theta = 37^{o}$ $\beta = 38^{o}$

Note: Monitoring system programmed for 230 ms time delay; α and β are acute angles measured from horizontal reference line, θ is true angle of impact.

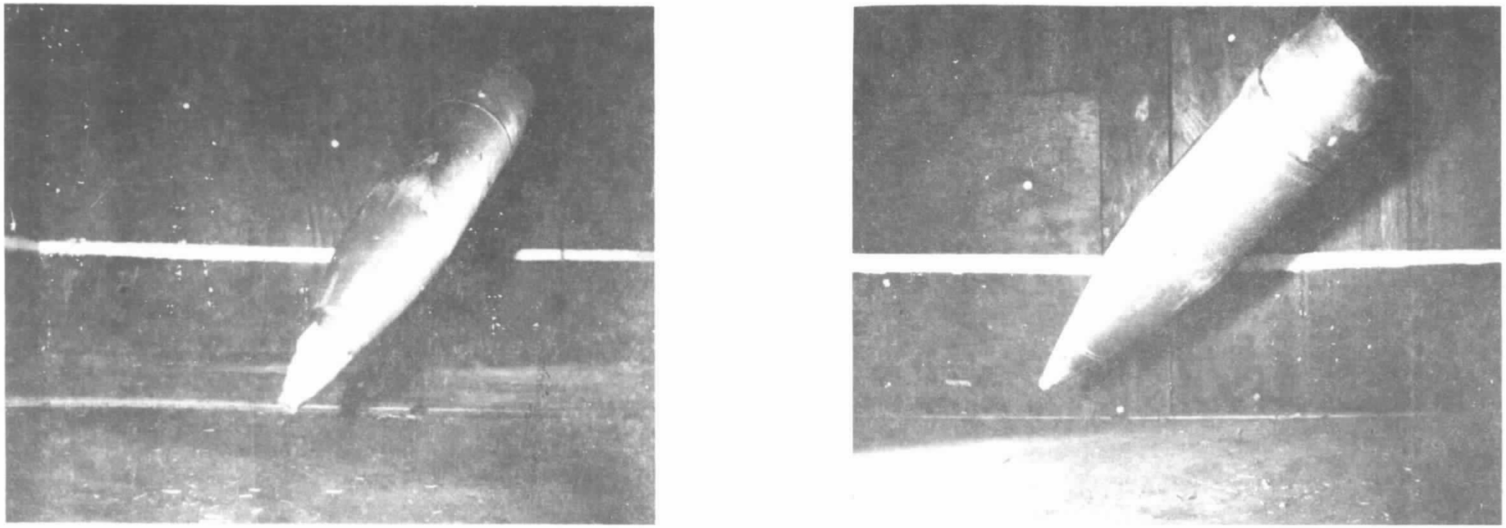
Figure H-2. Photographs of a Five Foot Drop Test, 45° from Vertical, Nose-Up Drop



$\alpha = 0^{o}$ $\theta = 0^{o}$ $\beta = 10^{o}$

Note: Monitoring system programmed for 216 ms time delay; α and β are acute angles measured from horizontal reference line, θ is true angle of impact.

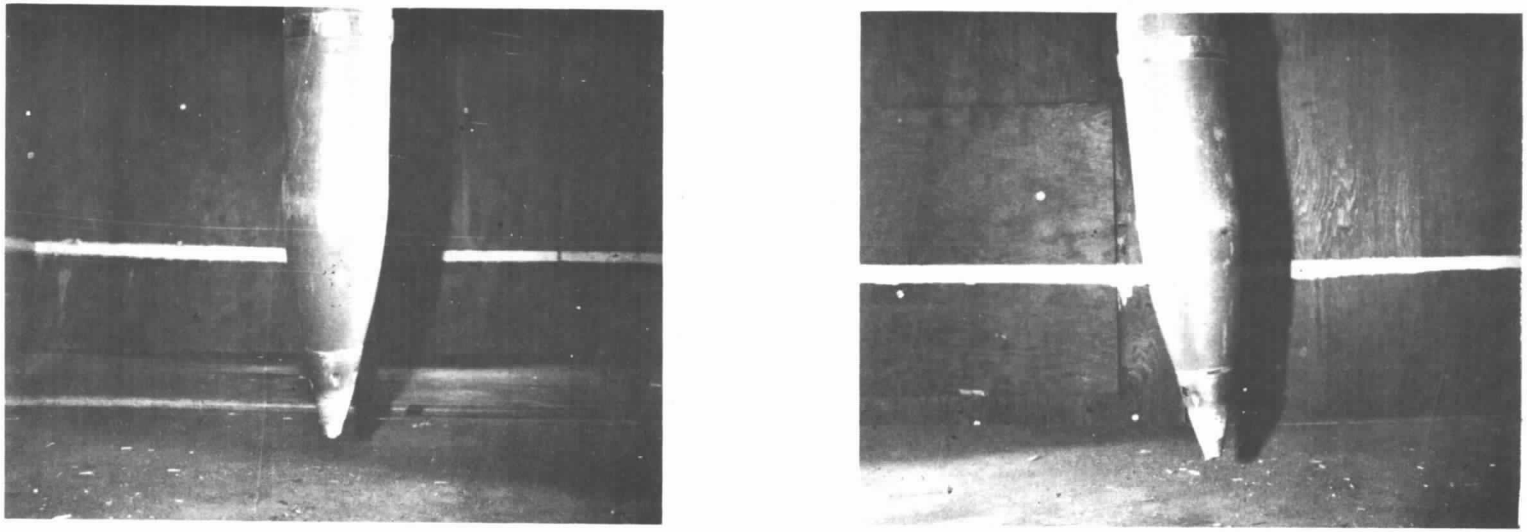
Figure H-3. Photographs of a Five Foot Drop Test, Horizontal Drop



$\alpha = 58^{\circ}$ $\theta = 44^{\circ}$ $\beta = 50^{\circ}$

Note: Monitoring system programmed for 230 ms time delay; α and β are acute angles measured from horizontal reference line, θ is true angle of impact.

Figure H-4. Photographs of a Five Foot Drop Test, 45° Nose-Down Drop



$\alpha = 89$ $\theta = 85^{\circ}$ $\beta = 85$

Note: Monitoring system programmed for a 238 ms time delay; α and β are acute angles measured from horizontal reference line, θ is true angle of impact.

Figure H-5. Photographs of a Five Foot Drop Test, Nose-Down Drop

APPENDIX I

Mechanical Shock Spectrum Analyzer

Design requirements

There were two major considerations in designing a mechanical structure to measure shock spectrum. First, the system had to simulate single degree of freedom systems whose natural frequencies corresponded to important frequencies found in Jolt machine response spectra. In looking at a typical spectrum, 100, 200, 500, 1000, 2000, and 3000 Hz seemed to be important frequencies. That is, a plot using those six data points yielded enough information to determine if a shock spectrum in the calibration test was closely correlated to the standard Jolt environment (defined in the Jolt subproject). The second design consideration was the requirement to adapt onto the Jolt arm. This was accounted for by threading the structure for direct attachment to the "nose-up" socket.

Natural frequency calculations

Cantilever beams were used to approximate the single degree of freedom systems. The maximum allowable dimensions were 5" in length, 1" in thickness, and 1" in depth. These maxima values necessitated using cantilever beams with end masses for the lower frequency arms. Therefore, the two governing expressions used in designing the beams were as follows:

(a) Cantilever beam

$$fn = 0.56\sqrt{\frac{EIg}{ml^4}}$$

where fn = natural frequency (hz)

E = modulus of elasticity (lbs/in^2)

I = moment of inertia (in^4)

m = mass per unit length (lbs/in)

1 = beam length (in)

g = gravity constant (386 in/sec^2)

(b) Cantilever beam with end mass

$$fn = 0.159 \sqrt{\frac{3EI}{l^3 (M+.23m)}}$$

where M = mass of end mass (lbs)

m = mass of beam (lbs)

After many calculations, six beams were chosen. Table I-1 lists these beams.

TABLE I-1. Beam Description-Mechanical Shock Spectrum Analyzer

Beam	Natural Freq (hz)	Length	Height	Depth	End Mass
1	118	5"	3/16"	1"	3/4" x 1" x 1"
2	202	4"	3/16"	1"	3/4" x 5/8" x 1"
3	517	3"	1/4"	1"	3/4" x 1/2" x 1"
4	898	3"	1/4"	1"	
5	1796	3"	1/2"	1"	
6	3592	3"	1"	1"	

Test and evaluation

After the structure was fabricated an experiment was made to determine the natural frequencies of the beams. A Spectral Dynamics SD3002 Mechanical Impedance System was used to measure the resonances. The structure was rigidly attached to a vibration shaker and the frequency was swept while monitoring the output of an accelerometer mounted at the end of each beam. Table I-2 compares the theoretical and measured natural frequencies of the structure.

TABLE I-2. Beam Resonances-Mechanical Shock Spectrum Analyzer

Beam	fn theoretical (hz)	fn measured (hz)
1	118	135
2	202	235
3	517	609
4	898	960
5	1796	?
6	3592	?

The results indicated that the measured frequencies were close to the theoretical frequencies. Some difficulty was encountered in trying to measure the natural frequencies of beams #5 and #6 because of resonances in the vibration table. However, since the lower frequency beams showed very good correlation the structure was considered sufficient for use in calibrating the Jolt machine. When the structure was subjected to the Jolt shock the measured peak accelerations of arms #5 and #6 agreed with the expected peak accelerations from the previously obtained shock spectra (assuming the theoretical values for the natural frequencies).

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